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ELEMENTS OF GLASS
AND
GLASSMAKING.

A TREATISE DESIGNED FOR THE PRACTICAL GLASSMAKER
COMPRISING FACTS, FIGURES, RECIPES, AND FORMULAS FOR THE MANUFACTURE OF GLASS,
PLAIN AND COLORED.

INCLUDING AN APPENDIX CONTAINING USEFUL
INFORMATION PERTAINING TO THE
SUBJECT.

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BY

BENJAMIN F. BISER.

CHEMICALLY REVISED BY J. A. KOCH, PHAR. D.

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PUBLISHERS' STATEMENT.

Though much of a fragmentary nature has been written of the making of glass and its history, no attempt has heretofore been made to bring under one cover information which will be of practical worth to those engaged in the manufacture of glass. The purpose of the present volume is to present the essentials of the art in the form of the greatest practical utility. The subject is much too large for the scope of any one book, but it has been the aim to include in this book the essential details, and to constitute a store of authoritative information from which the expert and the beginner alike can draw with profit.

To keep the book within convenient compass, all details as to estimates on factory construction, machinery, supplies, materials' etc., have had to be eliminated, but all such information, not already in the possession of the reader, can be secured at length by addressing the equipment, material and supply concerns whose advertisements can be found in The Glassworker, of Pittsburg, Pa., the newspaper of the glass trade in all its branches.

Glass and Pottery Publishing Co.
Box 555, Pittsburg, Pa.

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PREFACE.

The principal portion of the matter contained in the following work represents the contents of a glassmaker's private note-book; and while the facts and figures therein were collected for personal edification, it hardly seems necessary to make any excuses for their publication, since notwithstanding the multiplicity of books on the same subject, there seems to be none exactly adapted to the wants of the average practical glassmaker.

It has been the object to present the contents of this volume in a series of plain, practical essays, arranged in succession, as it appears to the writer, that to properly understand the aggregation, and proportionate association, of the elements of glass, it is necessary to first understand its principles and characteristics. It is for this reason that so much space has been devoted to the more important characteristics of glass, as the principles of definite proportion are dependent thereon. The various constituents of glass have also been given considerable space to afford a proper conception of their derivation, composition and effects, including simple tests and analyses for determining purity. An appendix has also been added, which contains miscellaneous information pertaining to the subject.

All known works of authority have been consulted in the preparation of this manuscript. Especial indebtedness is due to James Reed, who so generously contributed a large portion of the formulas contained in the work. In conclusion, the work is designed for the practical glassmaker; and the authur presents ***Elements of Glass and Glassmaking*** for his consideration, with the hope that, in some respect, it may contribute to the general fund of knowledge in glassmaking.

BENJAMIN FRANKLIN BISER.

INTRODUCTION.

As a people, we are prone to overlook the interest centering in the commodities that alleviate the discomforts of life. By no means the least of these commodities is glass. Surrounded by articles representing it in almost every conceivable form, perhaps a mosaic, a stained window, a piece of filagree work, a richly cut bowl, a common tumbler, or a bottle, may excite our passing admiration; yet, nine times out of ten, the inquiry—if inquiry at all—regarding its origin or production ceases with the simple definition:—"a product of sand," and the mind does not conceive the depth of romance underlying its origin or propogation. This fact does not only apply to those in the ordinary walks of life, but penetrates to the vital depths of the industry, reaching not only a large majority of those artisans who fashion it, but quite a few of those who create it; and while there always exists a superabundance of traditional data, inherited from generation to generation, father to son, so to speak, yet there is an almost absolute dearth of practical—to say naught of theoretical—information in possession of the average glassworker regarding the substance he daily gives form and figure.

Notwithstanding the universality of the present use of glass, its discovery was exeremely ancient, and its history is so resplendent with achievements, queer facts, and characteristics, that it is truly romantic. For many centuries the properties of glass have caused it to be admired, and sought by all classes, and some writers believe that it was in use to a greater extent among the ancients—especially among the Romans during the imperial period—than in comparatively modern times. Dr. Johnson so ably illustrates a portion of its present uses in the following, that we quote: "Who, when he first saw the sand and ashes by casual intenseness of heat melted into a metalline form, rugged with excrescences and clouded with impurities, would have imagined that in this shapeless mass lay concealed so many conveniences of life as would in time constitute a great part of the happiness of the world. Yet, by some such fortuitous liquefaction was mankind taught to procure a body at once in a high degree solid and transparent, which would admit the light of the sun, and exclude the violence of the wind; which might extend the sight of the philosopher to new ranges of existence, and charm him at one time with the unbounded extent of the material creation, and at another with the endless subordination of animal life; and what is yet of more importance might supply the decay of and succor old age with subsidiary sight. Thus was the first artificer of glass employed, though without his own knowledge or expectation. He was facilitating and prolonging the enjoyment of light, enlarging the avenues of science, and conferring the highest and most lasting pleasures, and was enabling the student to contemplate nature and the beauty to behold herself."

With all of its commendable qualities to adapt it to universal use, glass is still a peculiar substance—unlike any other—and its definition is rendered difficult by the subtleness of its nature, and the variability of its constituents, each of which contributes largely to its peculiar quota of characteristics. Not by any means the least remarkable fact regarding it is its creation by the combination of materials plentiful in nature,of themselves crude and opaque, yet by fusion transformed into a lustrous, limpid, transparent substance which can be wrought by heat into forms and designs unrivalled in beauty. When in a melted state it can be poured like oil and molded to suit the will. As it cools it assumes that peculiar state of viscosity, in which its ductility is such that it can be drawn into hair-like strands which can be woven into cloth or tied in knots. Its elasticity is such that it can be be blown to a gauze-like thinness, so as to float upon the air. As it hardens, it becomes exceedingly brittle, and assumes a brilliant lustre and polish, yet retains its elasticity to such an extent that a globe of it filled with water and hermetically sealed, if dropped upon a polished anvil will recoil two-thirds the distance of its fall and remain entire. It is a non-conductor of electricity, and a poor conductor of heat. If a ball of melted glass is dropped into cold water it produces no agitation in the water until its temperature is reduced to about one-half. Perhaps the most peculiar characteristic of glass is the change it undergoes by repeated or prolonged heating, when it becomes divitrified or porcelain-like and crystalline in structure, (under ordinary circumstances glass is non-crystalline in structure). When exposed to the action of the elements any great length of time it assumes a variegated hue termed iridescence; this latter peculiarity is now given commercial importance, and is frequently produced artificially. Innumerable other peculiarities could be mentioned, and it is these queer facts which characterizes it as a substance peculiar to itself.

In a certain sense glassmaking is not only one of the oldest, but one of the newest occupations, and herein lies the romance of an art dominant, virtually blotted out of existence for centuries, and restored. Its origin is unknown, but we have reasons to believe that it is as old as the earliest civilization, even as ancient as the art of brickmaking. Glass objects have been found under circumstances and in places indicating that they were in use before man learned to manufacture iron into useful forms; and if glass was coeval with bronze, why may it not also have existed in the age of stone?

Ancient writers—especially Pliny—tell us a wonderful story, of its discovery by Phoenician merchants returning from Egypt to Syria with a cargo of natron (crude soda). Storm driven they landed on the sandy beach at the mouth of the river Belus, which flows from Mount Carmel and enters the sea near Tyre and Sidon; and while cooking their food, rested their cooking utensils on blocks of the natron. The heat from the fire caused the natron to melt and form a flux that reduced the sand to glass. But this story is purely a fable, as the result would be impossible. As to the probable discovery of glass we are led to believe that there is little doubt that it was the result of an accident; some one had the acuteness to notice its fortuitous production; but who, exactly when, or where is absolutely unknown.

A coarse colored glass is frequently produced in metallurgical operations as an accident; and again, when vegetable substances which contain silica and an alkali (as straw) are burned, glass is very often found. The Egyptians were proficient in metallurgical operations, and for argument suppose it was discovered in the early days of metallurgy. The Egyptians ascribe the invention of this art to Osiris. In Gen. IV:22, "Tubalcain, an instructor of every artificer in brass and iron," takes the invention back when the first man was living. Metallurgy evidently had some influence on the early manufacture of glass, as the oldest specimens are always colored, which by analysis shows the coloring agent to be of a metallic nature. Klaproth concluded that the variability of composition of the different ancient colored specimens showed evidences of being remelted metallurgical slags. Some writers think there was a possible chance for its discovery in connection with the art of glazing pottery. The Egyptians sometimes burned large heaps of straw and vegetation, and to this some attribute the discovery of glass by that people.

The earliest traces of its manufacture are found in Egypt. Archaeologists have discovered sculptured designs, representing glassblowers at work, which were made centuries ago, and on the rock tombs of Thebes you may see pictures of artisans blowing the shapes of glass through long pipes. There is an unmistakable evidence of glassblowing figured on the walls of the tomb of Mestaba of Tih, of the fifth dynasty, the earliest representation yet discovered—a time so remote that it is impossible to give it a date in years—say, for instance, 4000 years B. C. Mummies in the tombs of Memphis wear necklaces of paste-glass beads. Memphis was built by Menes I, king of Egypt. Manetho figures his reign 5004 B. C., but Egyptian chronology is uncertain. On the tomb of Beni-Hassan are representations of glassblowers. These tombs are supposed to be of the period of Osirtasan I, 2500 to 3000 B. C. But even given the date of the period in which these inscriptions were executed, the art certainly antedates by at least some centuries these periods, as development was slow at that day and centuries were certainly required to evolve the skill and perfection necessary to develop the art to the degree of which the ancient specimens are evidence. In general, it is believed that its discovery and use originated in Egypt, as its most ancient monuments are of that country. But it is not easy to trace the progress of glassmaking there. The objects found there rarely bear inscriptions, but the earliest specimen of glass bearing an inscription from which its date might be ascertained, was found in Thebes by Signor Drovetti many years ago, and is now in the British Museum. The hieroglyphics determined it to be of the eleventh dynasty, about 2423-2380 B. C. We conclude that glass was undoubtedly invented in, and radiated to all other countries from Egypt, as the channels of communication can be traced. The Phoenicians also lay claim to its discovery, but they cannot be substantiated.

As an industry glassmaking spread from some common center. It grew and multiplied until it reached a point of development which in some respects has never been excelled, and perhaps never equalled. If the Syrian, Greek and Latin versions of the Old Testament are correct, glass was placed in the same category as gold. Vessels still exist of fine blue opaque glass edged with a comparatively thick plating of gold. Herodotus saw in the temple of Hercules at Tyre, a statue or column of emerald glass. Pliny speaks of a glass statue of Serapis, thirteen and one-half feet high, and an obelisk sixty feet high composed of four emeralds, which Apion and Theophrastus saw in Egypt. The invention and ingenuity of the ancients was most remarkable in producing variety in glass, devising means of decoration, and methods of manipulation. Many processes now in vogue, which are supposed to be recent discoveries, have in reality been anticipated by the ancients. To demonstrate this: Among the relics taken from the tombs of Thebes are specimens of glass coins with hieroglyphical characters, which prove that the Egyptians must have been acquainted with the art of pressing glass, while hot, into metallic molds. This has always been considered a modern invention. The Egyptians pressed glass into figures of deities, sacred emblems; adapted for mosaic work; colored it to imitate precious stones; worked it into beads and necklaces, and used clay and wire molds with which to form cups, vases, etc. The so-called Portland vase, and the vase at Naples, are beautiful examples of the later ancient art, and illustrate their skill and proficiency in manipulating and fashioning glass. Their ingenuity which devised so many modes of ornamentation, so many shades of color—primitive tools and impure materials considered—demands our unbounded admiration. Circumstances seem to demonstrate that the industry was carried on by many artificers, each working on a small scale.

But a crash came to all of the splendor when the barbarians of the northern countries blotted out the power, and even seriously imperiled the civilization, of ancient Rome. (It may be remarked that the Romans prior to this time had attained virtual supremacy in the art of glass). In the mental and material prostration following the barbarian conquest, and during the dark ages, the art of glassmaking became but a flickering flame, preserved from total extinction by the church in the one branch of the industry, that of mosaics and stained windows; and ancient glassmaking for centuries was virtually a lost art. Eventually Venice was able, in secret, to recuperate her lost art, and at one time whole streets of Tyre were wholly occupied by glassworks. The Venetians did all they could to retain their secrets intact, even removing their factories to the island of Murano, in order to better guard the monopoly. So useful were the glassmakers at one time in Venice, their industry contributing such large revenues to the Republic, that to encourage those engaged in it to remain in Murano, the Senate made them burgesses of Venice; allowed them to wear a sword; exempted them from the payment of all duties and taxes, and allowed nobles and patricians to marry their daughters without loss of nobility, which also descended to their issue. So stringent were their mandates that the Council of Ten forbade glassblowers from revealing the secrets of the art to strangers under extreme penalties. An extract from their laws in 1474 reads: "If any workman conveys his art to a strange country to the detriment of the Republic, he shall be sent an order to return to Venice. Failing to obey, his nearest relation shall be imprisoned. If he still persists in remaining abroad and plying his art, an emissary shall be charged to kill him."

At one time the glass industry in Italy was governed by a council of glassworkers, composed of six glass-masters, who were elected during the Christmas festivities by a majority vote of their fellow-workmen, to serve one year. The orders of this council were imperative, and so recognized in the administration of the industry. It established the wages paid to the workers, allotted the number of workmen to go to any foreign factory, and decided all questions pertaining to the welfare of the business. An oath was required from each man before starting to any foreign factory, obligating him to maintain secrecy; zealously guard the interests of the craft; uphold its traditions; strictly obey all of its rules and laws, and return to Altare and report to the council not later than the feast of St. John (August 29th) each year, relative to the year's activity. So great was the desire to impart mystery to the art, that in times past it was the custom of the workmen when "pot-setting," to attire themselves in the skins of wild animals and goggles, to protect themselves from the heat, and then parade the neighborhood thus attired to the great alarm of the children and women. Even at the present day there still remains a fund of traditions and heriditary data, that in many cases is much revered.

But, while the Venetians especially, did all in their power to retain their secrets, and control the monopoly, the glassblowers chafed under restraint and gradually wandered from the folds of the councils and ignored their mandates, lured, no doubt, by inducements held out by foreigners, until Venice was compelled to compete with young but ambitious rivals, born with the grey dawn of a later day European civilization, who justly claimed a portion of what was regarded as the heritage of Europe. And thus Egypt, Rome, Venice, Germany and Bohemia, became century marks in the later history of glass, and glass became a criterion of civilization.

Glassmaking of today is a new art, because but perhaps a century and a half have elapsed since it began to emerge from the almost total eclipse it experienced during the dark ages, and to the nineteenth century must be assigned nearly all the improvements which have placed it once again among the arts. Still, as we have remarked above, the ancients were familiar with many processes which we consider new; and many of our improvements of today are simply lost processes rediscovered. As a whole, the constituents, their proportions, methods of aggregation and association, and the manipulation of glass, are along the same general lines that guided the ancients; and we have been but regaining that which has been buried beneath the dust of centuries.

DEFINITION. COMPOSITION. CLASSIFICATION.

Definition.

The title "glass" is applied to such a perplexing variety of substances, both chemically and commercially, that it makes an exact definition, embracing all substances to which it is properly applied, extremely difficult. It would be comparatively easy to select a single piece of any particular glass and define it, or two dissimilar kinds; but not so when we conceive the innumerable variety of glasses, all of which contain conditions of similarity.

A composite definition may be suggested as follows: A transparent solid formed by the fusion of silicious and alkaline matter, which assumes while passing through said state of fusion at a temperature sufficiently high a fluid condition, and, as the temperature falls, passing from the fluid through a ductile, viscous state of a solid—devoid of crystalline structure, impervious and impenetrable to both gaseous and liquid fluids—a hard, brittle mass which exhibts, when broken, a lustrous fracture.

Any product of fusion that is hard, brittle and vitreous, is chemically termed glass. Commercially the title designated (with few exceptions), the silicates, or compounds of silica—a fusion of two or more simple silicates. A silicate is a salt of silicic acid; a compound of silica with one or more alkaline or metallic oxides.

The difficulty of an exact definition of glass lies in the fact that while glass is regarded as a chemical compound—a silicate—unlike most chemical compounds it has no fixed definite composition in its several varieties, yet the fundamental principles of all commercial glass are decidely similar.

Composition

Glass consists, generally speaking, of a mixture, (rather than a compound, as there is difficulty in determining the molecular composition of the constituent silicates), of two or more silicates united by fusion into a homogeneous, hard, brittle mass. The nature and molecular composition of these silicates determines the variety or nature of the glass, according to the proportion of the base or bases associated with the silica. Silica (termed the dioxide of silicon, (SiO_2) predominates as the essential element of virtually all manufactured glass. Combined with the silica are such bases as potash, soda, lime and lead. The bases may be termed alkali-metallic oxides, and with the silica comprise the fundamental constituents of manufactured glass. Oxides and materials other than these are used as auxiliaries for special purposes, as de-oxidizing and de-colorizing agents, and for imparting special colors, and properties of manipulation to the product of the combination of the resultant silicates of potash, soda, lime, etc. As an example: Flint glass is composed of silica, potash, and lead; or silica, lime and soda; a double silicate in either case. Window glass is a ter-silicate of potash, lime and soda. These silicates are not separately formed and then fused, but are simultaneously fused together by a double though continuous process without any break in its continuity, by being mixed and charged, and then fused to completion in the pot or furnace of the glassmaker.

At least one alkaline base is always necessary in the creation of a silicate, and the quantities of the various constituents vary according to results desired. These proportionate quantities are determined by experience establishing formulae for the various glasses. These formulae constitute the basis upon which a glassmaker establishes his results. We have stated that glass is a silicate, single, double, etc.; also that a silicate is a salt of silicic acid, (a compound of silicic acid with one or more alkaline or metallic bases), but it is well to further illustrate the subject. Analysis of a certain sample of glass will determine the quality or quantity of its constituents, but it does not set forth or determine the manner of its association. It is known that this association is affected by heat, but it requires a further investigation than any analysis to determine the relationship that binds them together, and what chemical or physical changes heat develops, to convert these substances into an amorphous transparent body. If we take the different constituent substances of any particular kind of glass, and by mechanical means reduce their particles to the most infinitesimal size, and create a most thorough admixture of them one with another, there is yet no affiliation of the molecules; no adhesion or viscosity of substances; and no combination of atoms ensues, because this is a physical or mechanical association. Hence, while it is of paramount importance in preparing the batch, as it facilitates the atomic combination when chemical action does ensue, yet of itself it effects no direct combination or molecular change of substance.

Prior to any molecular change, the molecules of a given substance must become disintegrated and decomposed, and their atoms be reassembled into molecules of new compounds; hence, the first necessity is to break the cohesive bonds of the molecular structure and release the atoms. It is known that the cohesion between the atoms of a substance is least in a liquid or gaseous form, and for this reason it is necessary to reduce the mechanical mixture to a fluid condition. Heat is regarded as a mode of motion—molecular motion—and supplies the agent now in question, and develops, when applied to this mixture, molecular energy sufficient to create fusion of the substance involved; then supposing that by fusion the substances are reduced to a fluid condition, and a general separation of atoms has ensued. Nature has supplied a certain form of general attraction called chemical affinity which, the moment the cohesive bonds are broken, asserts itself and re-assembles the atoms, and arranges them into molecules of new substances and compounds determined by the nature of their affinity, as the atoms of another substance, sometimes combining in several different proportions. Silica is a prominent example of the latter as it unites with the same metallic oxide in several different proportions, which is illustrated by the fomulae of the silicates of sodium, Na_2O, SiO_2: $_2Na_2O$, SiO_2: Na_2O, $_3SiO_2$: Na_2O, SiO_2. When we mix sand (the commercial representative of silica) with lead (PbO.) (Litharge), and reduce this mixture by fusion to a state of fluidity, it will be found that the silicia unites with the lead, forming silicate of lead; likewise the energy excited in the silica by heat is sufficient to decompose the carbonates of potassium, sodium and calcium, creating corresponding silicates of these bases. Hence it is not too much to assume, that if the result of the fusion of sand and lead is silicate of lead; of sand and potash the silicate of potassium; of sand and soda the silicate of sodium; of sand and lime the silicate of calcium; that if these same substances be mixed and fused together simultaneously the result will be a mixture of the same silicates. The silica combining proportionately with affinity.

While the special action of the various silicates will be given later, (see Raw Materials) it may be well to remark here a quality belonging to a mixture of silicates; which is the fact that the fusing point of a mixture is considerably lower than the mean of the fusing points of the silicates constituting the mixture. Thus a glass containing three or more silicates is more fusible than a glass containing two silicates only, but less perfect in structure. Experience teaches a glassmaker that as he increases his basic percentage of alkali, or oxide, in his batch, he lowers its point of fusion; but the product becomes softer, and while its density or specific gravity may have increased, yet its nature deteriorates. Silica is an essential element and the value of the product depends upon its proportion, and deteriorates as its percentage is decreased, or the percentage of alkali or base is increased. It is well to bear in mind regarding the fusibility of the different alkaline bases, that they contribute to the fusibility of the silicates consistent with proportion. Of these the silicates of sodium and potassium are most fusible, potassium exceeding sodium. The silicates of lead are sistent with proportion. Of these silicates of sodium and potassium than those of potassium, sodium or lead, but assist in the fusion in a combination of silicates.

While we are enabled to keep in mind the silica, alkalies, and oxides, comprising the principal constituents of glass, and even the approximate estimation of the quantity of each in the composition of the different kinds of glass, yet, even in different specimens of the same variety, the proportions are so indefinite as to exclude all possibility of any definite classification. Chemically there is such a variation in the composition, and commercially the names that have attached themselves to the various glasses are so innumerable, that a definite classification is impossible either on a chemical or commercial basis.

Glass is divided into two general classes: Natural and artificial. By natural glass is meant that produced entirely by natural causes without any assistance from man. These natural glasses are found principally in the vicinity of volcanoes, and are known as mineral obsidian, Peles' hair, etc. Other natural glasses are known as water glasses, and are found in certain springs, and absorbed in certain basaltic rocks. Artificial glass is that glass produced in the arts, and manufactures, including the various glasses of chemistry.

These two general classes (especially artificial) are sub-divided, and the divisions titled according to circumstances. As the natural glasses have no special bearing on the subject, we will confine our classifications to the artificial glasses. As a chemical classification, that of Ure, which while not absolutely correct in some details, will fairly illustrate the subject.

Soluble Glass.

A simple silicate of potassium or sodium, or both.

Crown Glass.

A silicate of potassium and calcium.

Bottle Glass.

A silicate of calcium, sodium, aluminum and iron.

Common Window Glass.

A silicate of sodium and calcium, sometimes potassium.

Plate Glass.

A silicate of sodium or potassium, calcium and aluminum.

Ordinary Crystal.

A silicate of potassium and lead.

Flint Glass.

A silicate of potassium and lead.

Strass.

A silicate of potassium and lead, still richer in lead.

Enamel.

Silica and stannate or antimoniate of potassium or sodium and lead (highly alkaline).

Much of the so-called flint or crystal glass of present manufacture, is generally a silicate of sodium and calcium, calcium superseding lead, and sodium superseding potash. The present opportunities for procuring raw materials nearly pure, have altered the constituent silicates to a great extent, both economically and effectively.

Commercial usage has apparently established four general and practical sub-divisions, viz:

1. Plate Glass.

Which comprises; rough plate, rolled plate, ribbed plate, and polished plate, having an approximately composition about as follows:

Silica	74%
Soda	12%
Lime	5.5%

II. Window Glass.

Which comprises; ordinary sheet; colored, painted or without color. The different methods of applying colors occasion different processes as: pot-metal, double or flashed, stained glass, or crown glass. Approximately the composition of window glass is:

Silica	73%
Soda	31%
Lime	13%

III. Flint Glass.

This term has an extensive application, and includes principally all common or lime flint, or crystal glass. Its approximate composition being about as follows:

Silica	73%
Soda	3 to 5%
Lime	10 to 12%

Lead flint is of greater specific gravity than lime flint, and is really the true flint glass. Its composition being about:

Silica	52%
Potash	14%
Oxide of lead	33%

Strass' is another flint glass very rich in lead, and used principally in the manufacture of artificial gems. Its composition being about:

Silica	38%
Lead	53%
Potash	8%

Optical glass may also be classed as a flint glass, being both a lead and lime glass.

IV. Bottle Glass.

This is a glass coarse and inferior in quality, used extensively for the commonest grades of bottles and hollow-ware, and is usually of a greenish, amber, or black color. Its composition is approximately as follows:

Silica	60%
Lime	20%
Potash	3%
Iron	0.4%

Alumina....................................0.1%

The iron and alumina occur as impurities in the minerals.

Other Classifications.

There are other varieties which might be mentioned. By special manipulation glass acquires such titles as, hardened or toughened glass, spun glass, ground, blown, pressed, cast, etched, engraved, figured, cut and embossed glass, etc.; besides the enamels, iridescent glasses, etc. To further illustrate, a classification according to place of manufacture might be made as: Venetian glass, Egyptian glass, English glass, Bohemian glass, American glass, etc. So taken as a whole, a definite classification is perplexing.

PROPERTIES OF GLASS.

(Chemical and Physical.)

Viscosity— Disintegration —Devitrification —Decay —Specific Gravity—Ductility and Elasticity—Expansion—Contraction—Tension—Tensile Strength—Metallic Combinations—Non-Conductivity—Iridescence.

The composition and the production of glass are curious, as it possesses peculiar chemical and physical characteristics which are entirely remote from any other material, and which isolate it as a capricious substance.

Viscosity.

Possibly the most important property of glass is its curious condition of viscosity. The crude materials when exposed to heat, decompose and generate gases, the evolution and expulsion of which carry off a major portion of all impurities, allowing the silicates to assume their various combinations and create glass, which assumes during its creation, by imperceptible stages, a liquid condition. In this condition it is too fluid to be adapted to the various processes of manufacture, but as the heat is diminished, or as it is chilled by exposure to air, it acquires a condition of viscosity; a condition intermediate between liquidity and solidity. In its viscous state it is ductile and tenacious, and is best adapted to the principal processes of manufacture. As the heat is allowed to diminish, or by a continued exposure to air, it rapidly assumes a solid condition; hard and brittle. We have herein a substance susceptible of a triality—so to speak—of condition; including a transformation from crude opaque to almost perfect transparency.

Disintegration.

When hot glass is cooled rapidly it becomes very brittle, especially if the pieces are thick. The reason for this is that the exterior cools more rapidly than the interior, which prevents a uniform contraction, and excites an undue tension that strains the molecular structure of the glass. By the exterior cooling while the interior is still hot, the molecules of the exterior become fixed, and as the interior cools it cannot contract; this produces an undue molecular strain. Glass in this condition is easily affected by changes of temperature, the weather, slight vibrations, etc., which break the strained bonds of cohesion. This property is best illustrated by small pieces of glass known as ''Ruperts' drops,'' or ''devil's tears,'' which are prepared by dropping small pieces of very hot glass into water, and removing them as quickly as possible thereafter. This gives a piece of glass with a hardened or chilled exterior, while the interior remains heated. Dumas explains this phenomenon of glass by stating: ''That as the outside is at once condensed or contracted by cooling, while the inside remains hot and consequently more distended, and when at last the central and more dilated parts of the drop become cool they must have retained points of adherence to the surface, and consequently occupy a larger volume than that which agrees with the temperature to which they are reduced. The central molecules therefore, must be much distended and exert a more powerful contracting influence on the surrounding parts. At the instant when a part of the envelope or outer portions is broken the molecules held by it briskly contract, draw in with them all the others and thus determine a multitude of points of rupture; and as the effect is instantaneous the particles move very rapidly, and drive out the air before them producing a sudden dilation and contraction of the latter.'' Again, if a similar drop made in the same way be taken and without fracture be buried in sand and reheated to the point of ductility and allowed to cool slowly with the sand, it will regain its normal condition, that is, the condition of glass whose molecular cohesion has not been strained; and it may be broken with the same kind of fracture and facility as ordinary glass. (See Annealing).

Devitrification.

Vitrification means a conversion into glass or a glassy substance by heat and fusion. Hence, devitrification means the act, or process of depriving glass of its lustre and transparency. This is another curious feature of all glass, and by undergoing this remarkable change glass becomes dull, opaque and porcelain-like. Devitrification is nothing more or less than a crystallization of glass, as ordinary glass lacks crystalline structure. Glass manufactured by ordinary processes is cooled suddenly, and the excessive internal tension thus caused is counteracted and reduced by annealing, but when the mass of metal is cooled slowly it acquires a crystalline structure.

A mass of metal repeatedly reheated becomes thoroughly devitrified in a short time, becoming tough, fibrous, hard in nature, difficult to fuse, and with a multitude of solid grains disseminated throughout; full of ''striae'' and semi-opaque matter. A moment's thought will expose in this feature, one of the glassmaker's arch enemies; a generator of cords and stones, and hard natured, lumpy glass, in a general way. The change of substance and structure is effected by repeated reheating; or takes place when glass is kept for any great length of time at a temperature near its melting point. If a workman in manipulating a piece of glass has occasion to reheat it an unusual amount, all phenomena of devitrification become manifest. The supposition is that the change of structure is effected by the partial separation of certain silicates (especially lime, as it is known that an excess of lime renders glass refractory and more liable to the action of devitrification); and by the more fusible alkaline silicates fusing at a temperature which is insufficient to melt the more refractory silicates.

While most glass is subject to this change, that of a complex composition is more liable to be affected; but those glasses with bases containing the earthly materials in excess, as lime, alumina and magnesia, devitrify easiest. Reaumer, Dumas, Pelouse, d'Arcet, and others labored to devitrify glass on an industrial scale, but with indifferent success. M. Garche discovered a product not many years ago which he called Ceramo-crystal, and in this discovery he obtained that which other savants had sought in vain. They endeavored to devitrify the finished article of glass. M. Garchey devitrified the glass first, and then gave it form, and by so doing created a definite product, and at a nominal cost. The product by this process is a ceramic stone; unaffected by temperature, water, or acids; and it will withstand a general wear and tear that free-stone will not.

Devitrified glass may be restored to a vitreous condition by fusion.

Decay of Glass.

Glass is subject to decay, both natural and artificial. We assume that glass is a remarkably hard substance, devoid of crystalline structure, impervious to both liquid and gaseous fluids, and with ordinary use resists the action of water and alkalies, and, with a single exception the action of all acids; preserving all its beauty, retaining its surface, and not losing the smallest portion of its substance by the most frequent use; but under circumstances of ordinary use only, as all glass is affected by caustic alkalies, especially in concentrated solutions which deprive it of its silicic acid. It yields readily to the corrosive action of hydrofluoric acid which decomposes the silicates of its composition, forming fluorides of its silica, and its metallic bases. Sulphuric, nitric, hydrochloric and phosphoric acids under favorable circumstances will also decompose certain varieties. Even pure water by prolonged action exerts a decomposing influence, especially if boiling. Emmerling in his investigations found that the action of boiling solutions (including water) upon glass is, within certain limits, proportionate to the length of time exposed, and amount of surface in contact with the action of the liquids.

Most acids in a dilute state, except sulphuric, attack glass less than water; but the solvent action of solutions of salts whose acids form insoluble calcium salts, as sulphates, phosphates, carbonates and oxalates, is greater than that of water, according to the concentration of the solution. Again, in solution of salts whose acid form soluble calcium salts, such as chlorides, nitrates, etc., the action is less than water and decreases with the concentration of the solution. It may be further said that with boiling liquids the action decreases in proportion to the decrease in temperature of the liquid. The foregoing may serve as illustrations of some of the principal agents of artificial decay. The causes of natural decay are: The atmosphere, the earth and their contents. The corrosive elements in all cases being moisture, assisted by carbonic acid and ammonia.

About the first sign of decay in glass is a colored tinge or iridescence, with a gradual increase to opacity, and finally decomposition. In a case of natural decay this process may require a lapse of years. But glass possesses internal enemies that are more formidable than its external, and an elimination of these internal influences would debar all exercises of natural decay, as the actual decay of the substance of glass is brought about by an excess of some of its constituents, generally its alkaline bases. It is known that the resistance to decay is increased or diminished as its composition varies to or from that required to form a definite chemical compound; and its constituents dissolve in about the same ratio as they are contained in the glass. Glass containing a large amount of alkali when exposed to atmospheric moisture, for instance, is attacked by the simultaneous action of the moisture and carbonic acid. On account of its excessive alkaline base, a soluble silicate has been formed, which decomposes more rapidly under the decomposing influences than would a glass rich in silica, leaving a surface pitted for the collection of additional moisture and consequent forces to aid in its destruction. Therefore, a glass rich in silica is better adapted for its durability. Some ancient glasses which were alkaline in structure owe their preservation to the presence of lime in their composition, although present as an accidental impurity. Some window glass, especially if of an inferior grade, presents illustrations of natural decay. A dullness of color after a lengthy exposure to the elements is a characteristic. This partial opacity is brought about by the combined action of the carbonic acid and atmospheric moisture, which develops an insoluble crystalline film of silica upon the surface of the glass, that is a result of the elementary action upon the silicates of its composition.

Laying aside the fact that chemical action has been determined as the principal agent in the decay of glass, other influences also physically exert disintegrating powers which seem sufficient to account for at least a part of its decomposition, or rather disintegration. Windows exposed to sunlight absorb a certain amount of heat, which warms and expands them each day, and vice versa, they cool and contract each night. To accomplish this an infinitesimal pulsation of the molecules evidently takes place with every change of temperature and minute as these tiny pulsations are, they represent the expenditure of a large amount of energy. Joule calculated that a pound of glass in passing through 100 degrees C, had its molecules subjected to a force sufficient to raise 11,600 times its own weight to a height of one foot. Think then of the prodigious energy expended in a window pane which has been exposed to the heat of the noon-day sun for years, its molecules swaying with vibrations of temperature up and down. It is not the actual strength or force of the vibrations, but the number of times the tides of expansion and contraction have "ebbed and flowed" through its substance.

Surely this then is sufficient to break apart the bonds of mutual attraction and create strata and laminations. Irregularities of expansive power; conductivity; or radiation, may even account for irregularities in lamination. Hence, we can but assume that the dynamic influence of heat and cold accelerate the phenomenon of decomposition in glass.

Specific Gravity.

Refraction and Reflection.

From a point of view relative to the manufacture of the ordinary glass of commerce, but little attention is paid to its specific gravity, but for the grades of glass intended for the refraction of light, as, object glasses, lenses, artificial gems, etc., the specific gravity is of importance, as the light refracting power of a glass increases with the increase of molecular weight, and is artificially increased by the addition to its composition of materials which will add to its density, though density and power of refraction are not strictly parallel. To a very great extent the specific gravity of glass, like its brilliancy, varies with its composition; the heavier glasses being the most brilliant, as well as the softest. Hence, lime glass is lightest, bottle glass next, and lead glass is the heaviest. The temperature during vitrification also influences the density of glass, it being always least when the temperature has been greatest, occasioned possibly by a greater evolution of volatile matter.

A table of the approximate specific gravity of some of the different glasses follows:

Lime Glass, Bohemian	2.396	(Dumas)
Plate Glass	2.448	(St. Gobain)
Plate Glass	2.5257	(Faraday)
Plate Glass	2.439	(Muspratt)
Window Glass	2.642	(Dumas)
Bottle Glass	2.732	(Dumas)
Bottle Glass	2.715	(Muspratt)
Lead Glass (Crystal flint)	2.900 to 3.255	(Dumas)
Lead Glass (Optical)	3.300 to 3.600	(Dumas)

Ductility and Elasticity.

Ductility of glass is analogous to viscosity, and while in a viscous condition it can be spun into filaments of great length and fineness, or blown to such thinness as to float upon the air, and can be molded into any form, retaining in cooling its transparency and lustre. When cold it cannot be wrought, as it becomes at once hard and brittle. While glass may be termed the synonym of brittleness itself, yet its elasticity is such that when hot it may be spun into minute threads, which when cold may be bent, twisted, woven into cloth, and even tied in knots. Its elasticity is a remarkable phenomenon and exceeds that of almost any other substance. This property is best exhibited when in the curious condition of glass-wool; or if a ball of glass is let fall upon an anvil it will rebound two-thirds the distance of its fall; or again if two glass balls be made to strike each other with a given force their recoil will be nearly equal to the original impetus, due to their elasticity. When a substance is elastic it permits a play of its particles, so that they return to their original position when the disturbing force is removed.

Expansion and Contraction.

One of the effects of heat is expansion, or increase in volume. All substances expand when heated, and contract when cooled. Some of the effects of this phenomenon in glass have been mentioned. Heat is the result of molecular energy. The molecules of any substance are in a constant vibratory motion, and the velocity of this motion determines the degree of heat. As the temperature increases, the mutual repulsion of the particles of heat overcomes the cohesive attraction of the molecular structure of the substance into which it enters, making them less dense than before, thus enlarging their dimensions and causing what is termed expansion. (a) What is true of expansion is reversed for contraction, thus: Expansion increases with the increase of heat; contraction increases with the decrease of heat.

(a) See Order of Expansion, Appendix.

In the manufacture of glass the various processes of annealing are for the purpose of eliminating the deteriorating effects of contraction. The expansion of glass has also been duly provided for in manufacture, as of recent years the efforts of manufacturers to weld together glasses of different natures and thickness for commercial purposes have given rise to research upon the subject of expansion.

A report recently made by Dr. Schott, from which we quote, says: "That in the case of silicious glasses the co-efficient of expansion increases with the percentage of alkali." When one kind of glass is to be welded upon another it is not necessary that the co-efficients of expansion should be approximately equal. Indeed it may be advantageous, he further says, to superpose a second glass of very different expansibility, as the articles made are never called upon to withstand a temperature so great as that at which they were originally formed. In 1885 Tscheushner illustrated by means of glass-wool, that a glass rod composed of two halves of different co-efficients of expansion, but approximate solidifying temperature, used together must, when spun, produce spontaneously a curly fibre, the diameter of which will be:

$$D=s\,\frac{(2+t)\ (a+a')}{t\ (d-d')}$$

wherein a and a' are the co-efficients of linear expansion per 1 degree C, of the two glasses; t the solidifying temperature, and s the thickness of the thread. Compound glasses are thus increased in tensile strength and resistance to a change of temperature by combining at fusing temperature two separate glasses possessing different co-efficients of expansion.

It may be best to speak of contractility rather than expansibility, since it is the phenomena of cooling after fabrication which chiefly need attention. If two plates of glass be welded together, and after cooling the double plate is curved, the more contractile glass will be on the inside. If two such plates are molded on a curved surface, the more contractile being on the outside, then after cooling the inside layer is kept stretched, the outside layer being on the contrary compressed. A vessel so constructed would be similar to a thick walled vessel which had been quickly cooled; such a vessel breaks if the inner stretched layer is scratched. On the other hand, vessels are greatly strengthened if both the inside and outside layers of glass are in a state of compression. This is the case with vessels composed of a single kind of glass which have been rapidly cooled by plunging them in oil, (see annealing), or with vessels made in three layers, of which the middle layer is the most contractile, so that the outer and inner layers are kept in a state of compression. Vessels so constructed have an important advantage over those formed by cooling in oil, viz.: The properties of glass are not altered by subsequent heating.

Tension of Glass.

The tension and enforced equilibrium of a mass of glass rapidly cooled is exhibited by the application of an extremely hot substance to a cold piece of glass; or vice versa, which creates in the first instance an unequal expansion; in the second instance, contraction of the glass, which causes a fracture at or near the point of contact. A cold glass vessel immersed in very hot water will sometimes become badly fractured, dependent upon the uniform thickness of the walls of the vessel; tension being excited between the thick and thin parts. Sudden cooling at any one point of a heated piece of glass, as the impact of a moistened instrument, or the fall of a single drop of water, causes a fracture at that point. Glass workmen take advantage of this fact in their vocation.

Tensile and Crushing Strength.

The tensile strength of a substance is its resistance to an enforced separation of its parts (pulling apart). The tensile strength of glass is given at from 2,500 to 9,000 pounds per square inch, according to variety. The crushing strength has a higher estimate of from 6,000 to 10,000 pounds per square inch. The tensile strength of glass is considerably higher than that of granite. The crushing strength of glass and granite are about equal. Much depends upon the glass, how annealed, etc. The resistance is greater, of course, in glass well annealed, as there is less structural lamination and undue internal tension, than in glass improperly cooled.

Manufacturers have experimented in a direction to determine a method to increase both the tensile and crushing strength of glass, but to a certain extent without any important or definite result from a commercial standpoint. Their experiments have been conducted with the assumption that the fragility of glass is due to the cohesive weakness of its molecules, and that if the molecules could be forced closer together, thus rendering their mass more compact, the strength of the material would be increased. They have endeavored to bring about this result by cooling the glass in various ways. (See annealing).

Glass and Metallic Combinations Under Process of Heat.

It may seem strange, yet it is sometimes necessary to solder glass and metals together. This has not only been successfully accomplished, but the combinations may be carried to a greater extent. If glass be heated to the melting point of aluminum, (700° C,—1,292° F,) the aluminum may be spread upon the surface of the glass with an iron spatula, and the adhesion of the metal is vigorous. In like manner magnesium (M. P. 455° C,—850° F,) also adheres, but much more readily when heated; but, the facility with which it is oxidized renders it less suitable for the purpose. The same may be said of cadmium, (M. P. 230° C,—446° F,). Zinc at a moderately high temperature possesses similar properties, (M. P. 412° C,—773° F.) Ordinary plumbers' solder, alloyed with a small percentage of magnesium, can be spread on glass like wax. These alloys, however, are rapidly attacked by atmospheric moisture. Tin (M. P. 228° C,—433° F,)—alloyed with 10 per cent of aluminum spreads easily, and is more stable, but requires a higher temperature for its use. An alloy of tin with two to five per cent of zinc has been found to work well. In experimenting in this direction the glass must be perfectly clean, and no flux is required. It is advisable to moderate the temperature, as oxidation becomes energetic if it is raised too high. An ordinary soldering iron can be used.

Non-Conductivity of Glass.

As heat is generated by a motion of molecules, so it is transferred or conducted by the transfer of the motion of some particles to other particles.

Glass is a poor conductor of both heat and electricity, especially those glasses rich in silica. Thus those glasses rich in alkali make bad insulation. This non-conductivity of glass is a peculiar property; if we stand by a window on which the sun is shining, we feel the warmth of the sun, but if we touch the window pane we find it cold; yet if we take this same piece of glass and place it between us and an ordinary open fire, it will shield us from the heat, but will become rapidly heated itself. In the first instance it transmitted most of the heat, and in the latter instance it absorbed it. This is a remarkable peculiarity, and while plate glass may absorb but five per cent of sun heat, it will absorb ninety-four per cent of heat from a source of 400 degrees. Generally speaking it may be stated that glass transmits the luminous heat rays, and absorbs the non-luminous.

Richard Szigmondy, of Vienna, claims to have invented a new variety of non-conductive window glass which is opaque for heat rays. He claims for his invention, that a sheet of this glass one-quarter of an inch thick will absorb from eighty-seven to one hundred per cent of the heat striking it. A comparison of the features of this new glass with ordinary glass—say plate glass with an absorbing power of five per cent—makes it seem impossible in some claims at least. But if it is really opaque to luminous rays, it will keep a house cool in summer, and tend to keep it warm in winter, as glass non-conductive at one time, must be so at all times.

Iridescent Effects in Glass.

There is occasionally seen in examples of glass, (generally ancient), which have been subjected to a process of decay, a wonderful beauty of tints of much brilliance and vividness of color. This is termed iridization, and the cause of this pleasing effect is the separation of the surface of the glass into extremely thin films, which refract and decompose the rays of light, giving them a prismatic effect. Sir David Brewster expresses very poetically the following sentiment: "There is perhaps no material body that ceases to exist with so much grace and beauty, when it surrenders itself to time and not to disease." In damp localities, where acids and alkalies prevail in the soil, the glass rots as it were by a process which is difficult to study. It may be broken between the fingers of an infant.

This iridescence may be frequently observed in window glass that has been exposed to the action of the elements for a great length of time. That it is caused by the action of decomposing effects separating the surface into thin films or scales, may be shown by immersing the glass in water, which saturates the films and unites them temporarily into one transparent mass with the more central undecomposed portion, when the colors disappear until the water evaporates. As the water evaporates the films again become separated by the intervening air and the colors again appear.

It has been found that colored glass, especially blue, produces the most charming effects of iridescence. It may be said that the effects of iridescence are really due to the principle known in optics as "intereference," which is explained as follows: Color is caused by the vibrations of light waves of a certain definite length which, when they fall on the eye, give rise to the sensation of a certain definite color. The smallest rays impart the sensation of violet; the next in size, blue; the next, green; the next, orange; the next, yellow; and the next, red. When the wave lengths exceed those of red they do not affect the vision at all; and if the various wave lengths reach the eye at the same time the result is white light. Hence, interference may be interpreted as a retardation of certain wave lengths by which some are absorbed or extinguished, and others are allowed to vibrate and impart their respective colors. We have assumed that this intereference is effected by the filmy substance on the glass, but the nature of the film may not always be the same, in fact, is not always the same, and it is impossible to give one explanation of the causes which would apply to all cases. A thin film of any transparent substance applied to the surface of glass will produce interference; or the glass may be blown to such a gauze-like thinness that its own substance forms sufficient interference, and will glow with color; or again, glass may be so laminated that its upper strata will produce the necessary interference.

As to when, and how the film on the glass arises is still a question. The film does not always appear to have been derived from the glass; for instance, where it has been removed the glass has been found beneath quite smooth and polished. Peligot decided that the film was composed of silica and earthy silicates which may have been derived from the rain being impregnated with a certain quantity of silica, derived from the soil over which it ran. But while the exterior film may originate in this manner, the glass by continued exposure to the elements begins to undergo a change of structure, and the microscope will show that beneath this exterior film after removal, the surface of the glass is dotted all over with tiny holes and hollows; and a sign of extreme antiquity of glass is its laminations, being split in layers and flakes.

The nature of the glass modifies this structural weakening to a large extent, as it is greatest in glasses rich in alkaline bases. In the case of badly decayed glass the iridescence is not confined to the exterior films; acids will cause these to flake off easily by dissolving the silicates, when it will be found that the indented and irregular surface of the glass beneath will glow with rich, dark colors.

Iridescence has been artificially effected with fair imitations, by depositing very thin films of silicate of soda on the glass, but when attempts are made to change the glass itself to resemble and impart the glowing hues of antique specimens, nature demonstrates her supremacy, and her work is not easily duplicated. In Favrile glass, by a careful study of natural decay in glass, the effects of lustre and iridescence are obtained by arresting the process and reversing the action in a way to obtain the effects, and avoid the disintegration. The methods which have been successfully adopted apparently consist in so alternating the refractive power of the external layers of the glass that interference is brought about as if a film or some other substance were deposited. Such methods as the subjection of the glass to the vapor from volcanic ashes, and the combined action of heat, pressure and weak acids, have brought about very beautiful effects. The latter process has been patented in France and England by M. Clemendot.

COMPOSITION OF GLASS.

The preceding pages present as a synopsis, the definition, composition, classification, and some of the principal chemical and physical properties of glass. It is now the object to review the elements necessary in the practical composition of glass. As a preface to the following it is well to remember that it is almost impossible to lay down any rules for definite proportions of the different materials used in glass, as the composition of the different varieties is so variable as to preclude anything more than an approximate estimate under this heading.

Regularly organized companies are making the preparation of crude materials a specialty, and a glassmaker can offer no reasonable excuse on account of their impurity. Analysis and simple tests are available as an additional safeguard. A banishment of that "will-o'-wisp"—Luck—and a judicious exercise of common sense and careful judgment will almost invariably insure success; always remembering that, none are infallible—wise men make mistakes, fools make blunders. If a mistake occurs some one is to blame, and a little search will locate the trouble, then "mark it" for future reference. One thing more; don't "know it all;" experience is a wise teacher and its students are numerous, and can very often offer a good suggestion.

Raw Materials.

If we take a sample of glass and analyze it, and determine its constituents, their nature and relation, we discover that glass is composed of a silicate or silicates. Chemistry teaches us that a silicate is composed of an acid and a base, or bases; and experiment demonstrates that the predominating acid in the silicate glass is silica; the bases, lead, potash, soda and lime. It may be safely said that these comprise the fundamental elements of all commercial glass. To these, however, may be added the auxiliary elements, nitrate of soda, sulphate of soda, arsenic, antimony, manganese, etc., etc.

From a chemical point of view potash, oxide of lead, lime, etc., have

a tendency toward the same general effect in glass, yet none of these can be substituted for the other or its analogues, as their distinct necessity results in the production of difference of fusibility, ductility, hardness, etc.

Silica.

Silica constitutes the true foundation of virtually all commercial glass, and is the only constituent that is universal, entering as it does, into the composition of all its varieties. It participates in the constituency as an acid, which combines with one or more bases, either alkaline or metallic, and creates the silicate glass.

Silica is best defined from a chemical point of view, and its principal characteristics may be enumerated as follows:

Silicon or silicum, (Si 28.3) is found in nature very abundantly as silicon di-oxide, or silica (SiO_2) constituting flint, quartz, most sands and sandstones (proportioned one equivalent of silicon and one to three parts of oxygen).

When pure, it is a light white powder which feels rough when rubbed between the fingers, and is both inodorous and insipid.

Chemically, it combines with bases forming salts, called silicates.

It resists the action of all acids except a mixture of nitric and fluoric acid, with which it readily enters into a solution.

Silica is called an acid by most chemists because it is dissolved by the fixed alkalies.

It is classed as a non-metal because of its non-conductivity of electricity and lack of so-called metallic lustre, and is classed with carbon and boron. It resembles carbon, inasmuch as it is known in the amorphous state forming two kinds of crystals, which resemble graphite and diamond.

By nature it is quadrivalent, i. e.: Its molecules have four points of affinity or contact.

Of itself, silica is incombustible in open air, or in oxygen gas; even exposure to the flame of the blow-pipe effects no fusion or change of form. A reducing agent is necessary to effect its fusion.

While silica is present in all silicious glass, the relative proportion used differs greatly, not only in different varieties but in samples of the same variety, owing in part to the inequality of its distribution in crude materials. Almost the entire nature and quality of glass depends upon the amount of silica in its composition; its relative hardness especially depends thereon, although it is sometimes affected by the counteraction of the alkali or oxide used as a base. Lead, for example, tends to soften glass, making it more fusible and lustrous; while on the other hand, lime has a tendency to assist in hardening, making it more refractory and less susseptible to the action of acids and alkalies. An excess of alkali as a base glasses were of a soluble nature. And again, we owe the preservation of renders it soluble. Owing to the excessive alkaline bases some ancient other ancient glasses to the presence of lime in their composition, although there as an accidental impurity.

The resistance to melting and fusion increases with the percentage of silica used. Experience teaches the glassmaker that, as he increases the basic percentage in his batch, he lowers its point of fusion, but the product is softer; and while its density or specfiic gravity may have increased, yet its nature deteriorates in certain values. The resistance to corrosion and decay in glass also increases with the percentage of silica, provided the variation is not too great from or to that required to form a definite chemical compound. The conductivity of heat and electricity decreases with the increase of silica in glass; hence, a glass poor in silica is not suitable for electric purposes.

Silica is now used in glassmaking almost universally in the form of sand. This was also the practice among the ancients, sea and river sand being the earliest forms of silica used. In sand is presented the most available means for obtaining silica, not only from an economical point of view, but in many cases it is of greater purity and value as a material, requiring but a nominal preparation for use; glass made from natural sands being superior in every respect to that made from artificially prepared flint and quartz sands. Modern glass houses until some fifty years since, procured silica for the finer grades of glass by the expensive process of crushing and washing flint and quartz. The common title "flint glass" evidently originated therefrom. Even yet in certain European countries, where good sand is scarce, not only flint and quartz, but certain silicious rocks are used. Some of these rocks contain a large percentage of soda and potash. Some foreign basaltic rocks would require the addition only of a small percentage of lime to be productive of glass. (Insofar as the necessary constituents are concerned.) One of these rocks, St. Gothard granite, shows by analysis.

Silica	65.75%
Alumina	18.28%
Oxide of iron	trace
Lime	trace
Magnesia	trace
Soda	14.17%
Potash	1.44%

To which an addition of about ten per cent of lime would make a very fair glass.

There are various grades of sand, which contain different percentages of silica; but where freedom from color, perfect transparency and brilliance are essential, it is important to use the best grades of sand obtainable, as slight impurities, especially iron, even though present in but small quantities, will seriously impair all desirable properties in the glass. However, when quality is a consideration secondary to cheapness of production, the quality of the sand is not so essential, as both iron and alumina are sometimes purposely added. The chief impurities in sand are iron and alumina, and the alumina is generally in the form of clay, loam, gravel and organic matter. Some of these impurities can be removed by burning and washing, but the iron and most of the organic matter can only be removed or neutralized by chemicals. Iron is the most dreaded of all impurities, as it not only destroys the color of the glass, giving it a greenish cast, but it is exceedingly difficult to neutralize its effect. Manganese is used to counteract this greenish color by neutralizing with its purplish tint the green into that limpid whiteness of color so desired in glass; but glass so decolorized is liable under the action of sunlight to acquire a purplish tint. However, practically this does not affect the use of manganese. As to the allowance of iron in sand for any kind of glass, there should not be more than one-half of one per cent, while for the finer grades of glass the least amount of iron possible.

In examining sand as to its value for glassmaking purposes, microscopic examination is the best test, observing the following points: It should be perfectly white in color. It should not be very fine. The grains should be uniform, even and angular, rather than rounded. In very fine sand the grains are smooth and rounded, and can only be used with difficulty, and very uncertain results, as such sand is liable to settle to the bottom of the "batch" and melting pot, preventing an even mixture of materials, producing consequently a glass uneven in nature and quality. Another test for sand is an acid test, in which the sand is heated in an acid. Sand so heated should not effervesce; effervescence indicates the presence of lime. It should not lose color; loss of color indicates the presence of clay, loam, or other foreign substances. Oxide of iron can be discovered by boiling the sand in hydrofluoric acid, and dropping into the solution thus formed a few drops of yellow prussiate of potash in solution; the beautiful blue precipitate indicates the presence of iron in the most minute quantities. Use care in handling the acid and avoid inhaling the fumes that arise from it. Conduct the boiling in a small lead crucible, and heat it over a sand bath. Dilute the solution formed (when cool) with distilled water; pour into a test tube and add a few drops of the re-agent, using a glass rod or any convenient dropper.

These tests are simple qualitative tests and only indicate in a general way, the qualities of the impurities present. For an accurate knowledge of the quantity, a quantitative analysis is necessary.

The organic matter which carbonizes in the pot during the process of melting is removed as carbonic acid by the use of arsenic, which is termed the great decarbonizer in glassmaking, as manganese is termed the great decolorizer. These decarbonizers ars known as "brighteners," and purifiers. A great many glassmakers have adopted antimony and have discontinued the use of arsenic; economy suggesting the substitution.

Analysis and color are not always indicative of the quality of the sand, as there have been instances when two kinds of sand, shown by test and analysis to be precisely similar, have produced different results as regards both color and quality of glass. Some yellow sands contain less iron, for instance, than other white sands. As a general rule, most sand used in glassmaking occurs as sandstone, and is quarried in blocks, which must be crushed and prepared for use. In other cases while the sand occurs as rock and must be quarried, it rapidly disintegrates on exposure to air and moisture. At other quarries where the formation is saccharoidal, or sugar-like the sand rock has a very weak bond, and is rapidly detached from place with a pick, rapidly falling into a fine sand. All of these sands must undergo a process of preparation before they become suitable for glassmaking purposes, by a process of crushing (when necessary), washing and drying. Burning is sometimes necessary (being an expensive necessity) when the sand contains an excess of organic matter; as in some deposits of sand in which the available percentage of silica would be high, yet being so situated that the percolation of surface water for ages has carried so much decayed vegetable matter so far down through the deposit as to render actual burning necessary to restore whiteness of color, and free it from the excessive organic matter. The heat of the furnace in melting, however, is generally sufficient, the carbonized matter being carried off as carbonic acid by the use of arsenic as explained above.

While most of the sand used is quarried or mined, some glass is still made, as was the earliest glass, from sea and river sand; this generally being used, however, for the cheaper grades of glass. The quality of the sand is always an item of importance to the manufacturer of glass, and in many instances has determined the location of the plant for such manufacture. This was especially true in earlier times. England, France, Belgium, Austria, Sweden and America, each have their quota of good sands.

American sands, especially, show supremacy over all others, many of them being free from excessive organic matter and in an almost absolute state of purity, and the supply nearly inexhaustible. Throughout America are vast deposits and unmeasured veins, many of which show by analysis 99.90 per cent pure silica. This is especially true of the deposits found in the New England states, New Jersey, Maryland, Pennsylvania, Illinois, Missouri, Minnesota, and various other states.

England produces some very good glass, but her sands are not as good as others; Alum Bay in the Isle of Wight, furnishes probably the best, of which the following is an analysis:

Silica	97%
Alumina, magnesia, oxide of iron	0.2%
Moisture	0.01%

French sands are taken as a rule from the quarries in the forests of Fontainebleau. These quarries furnished sand for England, Belgium and Germany for some time. One analysis of this sand shows:

Silica	98.08%
Magnesia, oxide of iron	0.07%
Moisture	0.05%

Summing up the whole: Sand enters glass as its principal constituent, becoming the acid of its composition, giving it its hardness and strength in proportion, its so-called metallic nature, its limpid color (according to purity), its uniformity of manipulation and its brilliant transparency.

A Method of Analyzing a Compound to Determine Silica, Alumina and Iron. (Comstock).

Reduce the substance to an inpalpable powder in an agate mortar, and mix with three times its weight of carbonate of potash, or soda; and decompose at a red heat in a platinum crucible. The mixture is then digested in dilute muriatic acid which effects solution. Evaporate solution to dryness, using care in regulating the heat near the close of the process to prevent the dissipation of the chloride of iron in vapor, as it is very volatile. By evaporation the silica previously held in solution by the acid is deprived of its solubility, and by digesting the dry mass in water acidulated with muriatic acid, the alumina and iron generally present are taken up and the silica is left in a state of purity, which is collected on a filter, carefully edulcorated, heated to redness and weighed.

To determine the iron, a considerable excess of a solution of pure potassa is added to the clear liquid containing the iron and alumina, which throws down these oxides and dissolves the alumina. The per-oxide of iron can the nbe collected on a filter edulcorated until the washings cease to have an alkaline reaction, and well dried on a sand bath. Forty-nine parts of this hydrated peroxide contain forty parts of the anhydrous peroxide of iron. To determine the alumina the liquid in which it is dissolved is boiled with sal-ammoniac, when the alumina subsides. As soon as the solution becomes neutral, collect the alumina on a filter, dry by exposure to white heat, and weigh quickly after removal from the fire.

Bases and Other Materials.

As has been stated previously, the bases are necessary as reducing and combining agents with the silica in the formation of the silicate glass, and the fusibility of the batch is increased with the proporton of the base or bases present. The bases are commonly termed "fluxes," which technically is a name given to any substance that assists in the fusion of another substance. In addition to aiding fusion, the relative hardness of any glass decreases with the increase of the bases, (except lime). As to fusibility, the bases are about as follows: Lead, potash, soda, lime. As they are decomposed they generate the agitation in the pot or furnace which is so impertant, by allowing the escaping carbonic acid to carry off the ever present impurities.

Their adaptability as a base may be determined by their economical power as a reducing agent. The principal bases do not enter the batch in the form in which they are found in the glass. Soda, as an example, is not used as soda, but as the carbonate of sodium, sulphite of sodium, chloride of sodium, or as a nitrate of sodium. In the process of melting these compounds are decomposed, the soda uniting with the silica forming glass; the balance of the compound passing off as gas, or as impurities in the form of "glass gall," etc. The same process applies to the use of potash, lead, lime, etc.

Sodium Salts.

Sodium Carbonate (Soda—Soda Ash) $Na_2 CO_2$.

Sodium carbonate, commonly known as soda or soda ash, has materially displaced all other bases, and constitutes the principal base of most commercial glass at the present day. All glass, in fact, contains soda in some form, even the glass of the ancients was a soda glass, and the analyses of the most ancient glass known show in some cases an excess of soda. The chief source supplying the soda for the earliest glass houses was Egypt. It was called natron, and was obtained from the natron lakes of that country. It contained carbonate, sulphate and chloride of sodium, and was used in the proportion of about one part of sand, to three parts of soda. In more modern times, and until within the last few decades, the chief source of soda has been the ashes of certain plants, (chiefly those of the sea and seashore), Spanish barilla, Scottish and Irish kelp, the Spanish soda of Alicant, and the rochette of Syria. They were all impure and produced a glass inferior in every way. The Spanish barilla, considered the best, only contained fourteen to thirty per cent soda.

The difficulties experienced with these impure materials, supplemented by a prize of 12,000 francs offered by the French government, induced Nicholas Le Blanc to devise a process (1790) of converting chloride of sodium (common salt, Na Cl) into soda, which opened a new era in glassmaking. This process was in universal use until about 1863, and may be briefly described as follows: "Salt is decomposed with sulphuric acid, making salt-cake, which is sodium sulphate, containing more or less undecomposed salt and some impurities. This salt- cake is mixed with coal and limestone and roasted in large revolving furnaces. The salt-cake is decomposed, and the soda is carbonated, making soda ash, but mixed with a considerable amount of undecomposed salt, salt-cake, caustic soda, and carbon, together with iron from the roasting furnaces."

In 1863 Ernest Solvay devised the ammonia process which is simple and more effective. "The Solvay ammonia soda is made from a purified solution of salt charged with ammonia, and treated with purified carbonic acid. The precipitate after filtering and drying and heating is ready for the market, as an exceedingly pure carbonate." There is claimed for the ammonia process, the presence of less iron and carbon than by the Le Blanc process; and as it is the iron and carbon contained in impure sodas that is detrimental to the ideal crystal white a glassmaker prizes, this feature alone makes the ammonia process preferable.

Soda ash is used in glassmaking as 48 per cent, 58 per cent or as "dense 58 per cent." Densified ash is recommended in many cases, as it is less bulky in the pots and does not give off its carbonic acid too quickly before the glass is fully cleared. The general basic action of soda ash has been described in the introduction to the subject (bases). As a special action it may be said that it adds a brilliant lustre to glass, but unless it is unusually pure, it imparts a bluish-green tint which must be neutralized with manganese, or some oxidizing agent. One hundred pounds of soda ash loses during fusion 31.67 per cent by evaporation and volatilization.

It is customary for many persons to test the strength of alkaline solutions by the use of the hydrometer. The hydrometer may safely be used to compare different solutions of the same materials, but not of different materials.

The commercial valuation of soda ash is usually restricted to the determination of the percentage of "available alkali" contained therein. Without entering into any exhaustive explanation, it is important to say regarding soda ash and its various tests, that public attention a few years ago was drawn to an error made by many analysts in attempting to apply the English commercial test for soda to samples of alkali, soda ash, etc. The result of which error is to make the test indicate from one to one and one-half per cent. more soda than it contains by the proper test. It seems almost unnecessary to state that no comparison can be fair if one soda is tested by the so-called "Newcastle test," for example, and another by the test for actual alkali. The mistake of these incorrect tests originated in the fact that early chemists fixed the atomic weight of sodium at twenty-four; subsequent investigations have proved it to be twenty-three. Under this test the actual alkali ($Na_2 O$) is stated as 32/54, or 64/108, of the total sodium carbonate. The actual alkali in accordance with the true atomic weights of the elements in the compound is 31/53 or 62/106 of the total sodium carbonate. The effect of this error is to increase the nominal percentage of alkali by 1.3 per cent. (Newcastle test). Another still more incorrect test is the so-called "New York and Liverpool" method of testing alkali, which has been in use at least fifty years. Under this test the incorrect chemical equivalent for sodium carbonate ($Na_2 CO_3$) is employed, which calls for 32/53 or 64/106 of the total sodium carbonate, which gives 3.266 per cent more alkali than actually exists. To further illustrate the different systems of alkalimetry for soda ash, a sample containing 48 per cent. actual alkali by the New York and Liverpool test; by the English or Newcastle test would contain 47.11 per cent., or according to the English test for actual alkali it would contain 46.5 per cent., and by the way it is sold on the continent of Europe, by its strength in sodium carbonate ($Na_2 CO_3$), it would contain 79.51 per cent. Again, if the New York and Liverpool test equals 58.32 per cent., the Newcastle test would equal 57.34 per cent., the actual alkali test would equal 56.5 per cent., the Continental test would equal (sodium carbonate) 96.60 per cent. But this method of testing has always been, and is still used by the soda trade, especially in England; however, so long as buyers and sellers of soda understand the different tests, and know by which they are buying and selling, no harm can be done; but when the attempt is made to compare different makes of soda ash by different tests, confusion and trouble at once arise. It is not the purpose to burden the mind with any of the exhaustive chemical tests and methods of analysis, but we present an analysis which is simple and sufficiently accurate to meet most circumstances for glassmaking purposes. This analysis we take from the "Papermakers' Digest," viz.:

Soda ash is always bought to contain so many per cent. of soda, actual soda, Na_2 O, generally 58 per cent. This soda ash is crystallized sodium carbonate, deprived of its water of crystallization and is almost pure carbonate, $Na_2 CO_3$, or two parts of sodium-Na, and one of carbon C, and three of oxygen O.

Na equals 23......Na_2 equals 23x2 equals 46.
Put in the atomic weights we have:
C equals 12.........C equals 12x1 equals 12.
O equals 16.........O_3 equals 16x3 equals 48.

Total......106.

Now take out Na_2 O—Na_2 equals 23x2 equals...... 46.
O equals 16x1 equals 16.

Total...... 62.

or 62 parts in every 106 parts of carbonate are actual soda. Calculate to percentage 62/106x100 equal 58.3 per cent., for practical purposes 58 per cent.

For this analysis the following is necessary: Normal sulphuric, or hydrochloric acid; this can be bought or can be prepared. A solution of methyl orange (one part methyl orange in 1,000 parts of water). Use a plain burette, put on a rubber tube two inches long, a pinch clamp and a fine nozzle. Fill your burette with acid, and having obtained your sample, weigh out on a watch glass, already weighed, 53 grams of your sample; dissolve in a 1000 cc. flask one-half full of water; when all is dissolved make up to 1000 cc. with water.

Take 10 cc. out, put in a beaker glass and add a couple drops methyl orange; the color will turn straw. Now add cubic centimeter by cubic centimeter of your acid; as soon as the color shows change read off from burette how many cc. have been used. Shake up gently and add another drop; the color will change to dark straw, then red. The exact point to stop at is the moment of change to red, and note the number cc. used. e peat with a fresh portion of 10 cc. and note again the number of cc. used; and say we have from three different readings of burette: 9.4, 9.5 and 9.6.

9.4+9.5+9.6 equals 28.5÷3=9.5 average. Then we have: 53 grams to 1000 cc. diluted.

0.53 gramme—10 cc.—taken for test, takes 9.5 cc. and every cc. of normal acid, neutralizes .031 gramme of actual soda. So .031x9.5 equals total actual soda present .2945 grammes. This in percentage equals 2.945 divided by 5.300x100 equals 55.48 per cent, or is short by two and one-half per cent full of 58 per cent. This shortage is most likely to be caused by absorption of water.

Solubility of Sodium Carbonate (Dry) Na_2CO_3.
in 100 Parts of Water.

Temperature degrees. C.	F.	100 parts water dissolve.	1 part requires water.
10	50	12.6	7.94
20	68	21.4	4.67
30	86	38.1	2.62
35	95	59.0	1.69
45	113	46.2	2.16
50	122	46.2	2.16
55	131	46.2	2.16
60	140	46.2	2.16
65	149	46.2	2.16
70	158	46.2	2.16
100	212	45.4	2.20

Note—Centigrade degrees x nine-fifths+32=Fahrenheit degrees.

Sodium Sulphate (Salt Cake) Na_2SO_4.

Sodium sulphate is made by the action of sulphuric acid on sodium chloride. (See carbonate.)

Glauber's salt, crystallized sodium sulphate (Na_2SO_4 $10H_2O$) containing 10 molecules of water of crystallization, is soluble in 2.8 parts water at 15° C,—59° F; in 0.25 part at 34 deg. C,—93 deg F; and in 0.47 part of boiling water. On depriving Glauber's salt of its water of crystallization, 55.9 % of its weight, salt-cake or dried sodium sulphate is obtained. One hundred pounds of dried sodium sulphate loses during melt about 56.31 per cent.

Glass made with sodium sulphate is less liable to devitrify, or become ambitty, and will bear more lime than carbonate glass; hence gives a harder glass with a better polish, and less liable to sweating. Sulphate glass is of a bluish color, while carbonate glass has a yellowish tint.

Economy in cost encouraged the use of sodium sulphate, but it is being gradually replaced by the carbonate. A larger quantity of sulphate than carbonate, however, is required for the same amount of glass, as it requires from 130 to 150 pounds of sulphate to do the same work and produce the same quantity of glass as 100 pounds of carbonate; and its decomposition, and the clearing of the glass requires ten to twenty per cent more fuel than carbonate glass requires. It also contains more iron than the carbonate, and its fumes are destructive to pots, breast walls, etc. The adoption of sodium sulphate as a constituent of glass occurred about the middle of the last century, and was brought about by the researches of Gehlen. Glassmakers first proceeded very cautiously with sodium sulphate as a new ingredient, by mixing a small quantity of it with a large proportion of the carbonate; gradually increasing the proportion to equal quantities of each; and finally the carbonate was omitted entirely. This last gave them a cheaper material, but one that doubtless injured the color of their glass. The bluish-green tint imparted by sodium sulphate was ascribed by M. Pelouse, to the presence of iron, the correctness of which has since been proven. This defect he succeeded in eliminating to a certain extent, by the use of lime, which resulted in a sulphate, refined and productive of better results.

The use of sodium sulphate involves the introduction of ingredients which are not required when pure carbonate only is employed; as the decomposition of the sulphate by silicic acid is accomplished slower and with much more difficulty, and it requires a higher temperature to effect fusion than with sodium carbonate. Carbon is introduced generally in a proportion of one, or rather more than one equivalent, to two equivalents of the sulphate. The carbon abstracts from the sulphate one equivalent of oxygen; the sulphurous acid which is thus formed is displaced by the silica, and silicate of sodium is the result. The disengaging sulphurous acid being decomposed much quicker than the sulphate or salt cake, hence it aids fusion. There seems to be no fixed proportion of carbon necessary for the decomposition of the sodium sulphate, and it has been demonstrated that decomposition is materially assisted by the use of calcium carbonate.

Another detriment to the glass without a thorough decomposition of the sulphate by carbon or other agent, arises in the fact of the dissemination of undecomposed sulphate in large quantities throughout and on the surface of the glass. The fact of the difficulty of a uniform distribution of carbon in the "batch" so that each particle of sulphate may find immediately, for the purpose of its decomposition, the necessary quantity of carbon, has given rise to many inconveniences. Carbon has generally been used in the form of coal, charcoal, pitch, etc. These substances can be replaced—according to a foreign invention—by organic non-ferriferous substances with large contents of hydrogeneous matter. This becomes liquid at a much lower temperature than sodium sulphate, while it develops at a higher degree of heat, gases and vapors which exercise a reducing action. Such substances near at hand are mineral, vegetable and animal fats, and oils, as parafine, ozokerite, tallow, resin, resinous oils, tar oils, liquid and solid olefiant bodies (carburretted hydrogen) of the aromatic order and their derivatives. By these substances liquefying at ordinary temperatures the distribution is more uniform, and contact with the sulphate much closer; besides, the liquefaction occurring before the constituents of the batch have entered into fusion, insures a shorter melting period and a quicker and better reduction of the sulphate.

Sodium Nitrate (Chili Saltpetre, Nitre) NaNO$_3$

Sodium nitrate enters glass as an auxiliary base, in conjunction with other alkaline bases, in a proportion of about one to five, as an oxidizing agent, and is therefore a decolorizer in action. Its soda unites with the silica similar to other sodium compounds.

Its oxidizing properties facilitate fusion, and add purity to the glass and color by aiding in the expulsion of carbonaceous matter. One hundred pounds of pure saltpetre loses about 50 to 53 per cent. during melt.

Sodium nitrate is found in nature as an incrustation upon and throughout the soil of certain localities in dry, hot countries, as for instance, in Peru, Chili and India. The formation of these nitrates is to be explained by the absorption of ammonia by the soil, where it is gradually oxidized and converted into nitric acid.

Sodium Borate (Borax) Na B$_4$O$_7$+10H$_2$O.

Slightly efflorescent; soluble in 16 parts of cold, and in 0.5 parts boiling water; melts at red heat, and forms a colorless liquid.

This salt occurs in Clear Lake, Nevada, and in several lakes in Asia. It is also manufactured by adding solution carbonate to the boric acid found in Tuscany, Italy. It forms colorless transparent crystals, but is sold mostly in the form of a white powder.

Borax is a powerful flux, and is used in glass to facilitate fusion. It exerts a decided softening influence on glass by its greater generation of agitation during fusion, during which it assists largely in the process of purification. Many glassmakers, for reasons above, recommend borax as a preventative for "cords," "stones," etc., as by the increased agitation of pot contents many of the impurities causing "cords," etc., are dispersed and expelled. Borax glass assumes great fluidity, and is easily fused; hence the salt is not used in large quantities.

Sodium Chloride (Common Salt) NaCl.

Inasmuch as sodium sulphate and sodium carbonate are both direct products of the chloride, it is but natural to suppose that chemists should turn their attention toward dispensing with the process of conversion, and utilize the chloride in the manufacture of glass by a direct union of sand and salt, without the intervening process. But such efforts have been without much success, as about the only glass made by such method is a black glass for bottles made in England.

Mr. Chance thus defines a mixture of materials devised by a Mr. George Gore: "In which steam should be liberated throughout at a high temperature only, and therefore under the conditions most effective for decomposing the salt. In this mixture, sodium sulphate and carbon were dispensed with altogether, and they were replaced by a chemically equivalent mixture of sodium hydrate and common salt; these two ingredients being also in quantities chemically equivalent to each other, and representing together, as near as possible, the amount of alkali contained in the ordinary sulphate mixture. The mixture thus modified consisted of sand, cullet, chalk, common salt, sodium hydrate, arsenic and manganese. In the reaction which took place the sodium hydrate decomposed the salt at high temperatures and formed hydrochloric acid, and anhydrous soda; the former escaped as gas, and the latter united with the silica. Mr. Gore succeeded in obtaining by this process a transparent glass, but the cost of the caustic soda rendered the mixture more expensive than the sulphate."

POTASSIUM SALTS.

Pottassium Carbonate (Potash, Pearl-Ash) K_2CO_3.

The value of potash as a glassmaking material was known as early as the fifteenth century. Potash is more efficacious than soda in effecting fusion in the melting process, but more expensive. No coloring action is exerted by potash, but the brilliance of the glass is diminished by it to a certain extent. One hundred pounds of 72 per cent. pure potash loses 22.80 per cent. during melt.

Potash is not used now to any great extent. Some of the more expensive glasses, as "English flint," are potash glasses. Some few ancient glasses show from one to two per cent. which was probably derived by chance from the soda used at that time. Potash in early manufacture was made from the lees of wine, fern ashes, wood ashes, beet-cake, grape-cake, etc. It was generally made by lixiviating wood ashes, which results in an impure carbonate that must be calcined and refined as for glassmaking purposes the quality of the glass depends upon the degree of purification. Refined potash when calcined in a furnace until white is known as "pearl-ash." Potassium carbonate, the form in which potassium is principally used in glassmaking, is also prepared artificially from the sulphate by Le Blanc's method.

Potassium Nitrate (Saltpetre) KNO_3

Potassium nitrate is sometimes used as an oxidizing agent in the finer glasses.

Potassium nitrate occurs in nature like sodium nitrate; or it is manufactured by lixivating animal refuse matter mixed with earth and lime; also made by the action of sodium nitrate or potassium chloride.

Analytical Re-Actions of Potassium Compounds.

I. Add to a concentrated solution of a neutral potassum salt, a freshly prepared solution of tartaric acid. A white precipitate of potassium acid tartrate ($KHC_4H_4O_6$) is slowly formed. An addition of alcohol will facilitate precipitation.

II. Potassium compounds color the flame of alcohol violet. The presence of sodium, which colors the flame intensely yellow, intereferes with this test, it masks the violet caused by potassium, unless the flame is observed through a blue glass, or through a thin vessel filled with a solution of indigo. The yellow light is absorbed by the blue medium, while the violet passes through and can be recognized.

III. All compounds of potassium are white (unless the acid has a coloring effect), soluble in water, and not volatile at a low red heat.

LEAD.

Litharge, PbO. Red Lead, Pb_2O_3.

The use of lead as a glassmaking material is an English invention and originated during the seventeenth century. It was brought about by the use of fuel which required covered pots to protect the glass from the impurities originating from the fuel which had been substituted for wood. By covering the pots the action of the heat on the materials contained in them was so retarded as to require a better flux. Lead is a powerful flux, and promotes fusion at a very low temperature. Its use as a constituent of glass for artificial gems, outical glasses, etc., for which purposes lead glass, on account of its surpassing brilliance and density, is specially adapted, antidated its use by the English in their invention of "lead flint," and possibly suggested its use to them.

Lead is used in glass in the form of litharge, or as red lead. Litharge is obtained by exposing melted lead to a current of air, when the metal gradually becomes oxidized with the formation of a yellow powder known as "massicot." At a high temperature this fuses, forming reddish-yellow crystalline scales known as litharge. By heating still further, in contact with air, a portion of the oxide is converted into di-oxide (or per-oxide PbO_2), and a bright red powder is formed. This is red lead, or minium, which probably is a mixture or combination of oxide and dioxide of lead, PbO_2, PbO. Red lead is generally preferred in glassmaking on account of its finer state of sub-division, and it decomposes during the melting process into ordinary monoxide of lead and oxygen; the latter facilitating the removal of impurities. Ordinarily lead is used in glass in a proportion of about 33 per cent.

Lead glass is very dense and heavy (specific gravity 2.900 to 3.255—Dumas); has a greater power of refraction—the refractive power of glass is proportionate to its molecular weight or density; and is very brilliant. By nature it is "soft," is easily scratched, and is less liable to breakage when exposed to sudden changes of temperature. Lead is used in conjunction with the alkali-metallic bases, potash, soda, etc., but potash is its principal co-base. An excess of lead not only makes glass "soft," but it imparts to it a yellowish tint, besides having an injurious effect upon the pots. The yellowish tint imparted, however, can be masked by the use of oxide of nickel.

The silicates of lead are more fusible in proportion to the greater amount of base (in fact any glass is less fusible in proportion to silicate, more fusible in proportion to base), and with equivalents it will melt at a red heat. On account of the difference between the specific gravity of lead and that of the other materials, the use of lead is the cause of innumerable "cords" and "striae" disseminated throughout the glass. This trouble increases with the increase of density. The difference in specific gravity between lead and its co-base, potash, is so great that it is like mixing oil and water. For this reason the materials for lead glass must be carefully mixed and melted, and worked out promptly.

Lime and soda ash are gradually replacing lead and potash. While perhaps the so-called "lime flint" glass does not possess the surpassing brilliance of lead glass, yet its lustre suffers to the enhancement of its qualities of hardness, resistance and economy; but lead is better adapted for use in glass to be colored than lime, as lead glass assumes a finer, fuller and more lustrous color than lime glass. For this reason lead is sometimes added to lime "batches" for colored glass, making them susceptible to a better color and an improved quality.

Analytical Re-Actions.

Dissolve the lead oxide (litharge) in nitric acid, which makes lead nitrate, the only salt of lead which is easily soluble in water. To a solution of this salt add sulphuric acid. A white precipitate of lead sulphate is formed.

CALCIUM SALTS.

Calcium Oxide CaO. Lime.

Calcium Carbonate $CaCO_3$.

Calcium carbonate, $CaCO_3$, is one of the most abundantly occurring elements in nature, being found in the form of calc-spar, limestone, chalk, marble, shells of mollusca, etc., etc.

Calcium oxide, CaO (burnt lime) is obtained on a large scale by the common process of lime burning, which is the heating of limestone, or any other calcium carbonate, to about 800° C—1472° F. The result is calcium oxide, or lime, a white, odorless, amorphous, infusible substance of alkaline taste and reaction.

The use of lime as a constituent of glass is comparatively a modern discovery, although nearly all glass of all ages and countries contained it in an indefinite proportion (ancient glass three to eight per cent.). But it was generally present as an accidental impurity, yet to its presence we owe the preservation of the most ancient specimens of glass. Its definite use, and proper proportion, however, was arrived at slowly and by experiment. Lime was originally used in the form of chalk, which possesses a freedom from iron (and iron is as detrimental to color when present in lime as in any other material). Lime is a very important element in glass, and it enters its constitution as an alkaline base—being classed as an alkaline earth—but its original use evidently designated it as a cheap substitute for lead, and its alkaline co-bases, potash and soda, without any determination of its true merits, which have been developed by increased and continued use.

An approximate proportion for the use of lime is about as follows: Plate glass, 5.5 per cent; window glass, 13 per cent; lime flint, 10 to 12 per cent.; bottle glass, 20 per cent. It is chiefly valuable in promoting fusion, supplying stability and increasing insolubility of the glass if used in proper proportion, but if used in excess it retards fusion, produces a milky appearance and makes it hard and liable to devitrify. Lime is introduced in the "batch" as carbonate (chalk limestone, etc.); as oxide (burnt lime); or as hydrate, $Ca(OH)_2$, (slacked lime). The use of calcium hydrate is nearly obsolete, as the oxide and the carbonate are supplied in a condition that dispenses with the laborious and unsatisfactory process of slacking.

In regard to the special action of lime, it may be stated that, while it has been substituted for lead, its specific gravity is less; and while it adds lustre to the glass, it does not impart the brilliance that lead does. Lime increases the hardness of glass without coloring the product, and a fact worth mentioning is, that while chalk and limestone are both carbonates, glass made with limestone is harder and cools and sets quicker than that made with chalk, which is possibly due to a general presence of magnesia in limestone. Lime can be used in a much larger proportion in conjunction with sodium sulphate than with sodium carbonate. This is advantageous, especially with window glass, as with an increased quantity of lime the glass becomes harder, assumes a better polish and is less liable to surface exudation, technically termed "sweating."

Lime is now obtained, commercially, in a finely ground condition and pure in quality, either as limestone or burnt lime. Most lime in burning absorbs a certain amount of those noxious elements, carbon and iron, and where burnt lime is used, that burnt with wood is recommended. The use of carbonate in the form of limestone is gradually being extended, and indeed can be recommended, inasmuch as it can be obtained finely ground and pulverized, and is just as available as the ground burnt lime, besides being cheaper. The especial recommendation for ground limestone (carbonate) is on account of the greater agitation resulting in the "batch" from the use of limestone in its raw state. It is apparent to any intelligent glassmaker that to drive off the carbonic acid gas from the limestone before putting it in the furnace must take from it a very valuable ingredient useful in producing glass. If the disengagement of the gas occurs in the furnace, the effect of its agitation is to help very materially in the process of clearing and cleaning the glass of impurities; besides the decomposition of the ground limestone is slower than burnt lime, and this slow decomposition tends to continue the fining, or cleaning, process to the very end of the melt.

One hundred pounds of calcium carbonate loses about 44 per cent during the melt, hence the use of about 50 per cent more of ground limestone is recommended than burnt lime. One hundred pounds of hydrate (slacked lime), loses about 28 per cent during melt.

Method of Analyzing Calcium Carbonate.

Take a known quantity of calcium carbonate and expose it for about one-half an hour to a full white heat. By this means the carbonic acid gas expelled entirely, and by the loss in weight the quantity of each ingredient is determined, supposing the carbonate to have been pure.

In order to ascertain that the whole loss is owing to the escape of carbonic acid, the quantity of this gas may be determined by a comparative analysis. Into a small flask containing hydrochloric acid diluted with two or three parts of water, a known quantity of limestone (or carbonate being tested) is gradually added, the flask being inclined to one side in order to prevent the fluid from being flung out of the vessel during effervescence. The diminution in weight experienced by the flask and its contents, indicates the quantity of carbonic acid which has been expelled. Should the carbonate suffer a greater loss in the fire than when decomposed by an acid, it will most probably be found to contain water. This may be ascertained by heating a piece of it to redness in a glass tube, the sides of which will be bedewed with moisture if water is present. Its quantity may be determined by causing the watery vapor to pass through a weighed tube filled with calcium chloride, by which the moisture is absorbed.

Analytical Re-Actions.

I. Dissolve calcium carbonate in hydrochloric acid until the acid is neutralized, and add either sodium potassium or ammonium carbonate, and a white precipitate of calcium carbonate $CaCO_3$, is produced.

II. Calcium compounds impart a reddish yellow color to flame.

BARIUM CARBONATE $BaCO_3$.

Barium occurs in nature chiefly as sulphate, or heavy spar, $BaSO_4$, but also as carbonates or witherite, BaCo, and its compounds closely resemble those of calcium (lime), being also like lime, an alkaline earth.

Barium is used in glass as barium carbonate, $BaCO_3$, but on account of its cost and impure state, it has not found its way into very general use. A witherite or carbonate comparatively pure, and especially free from iron and other impurities, was scarcely obtainable, and only at high prices. These objections, however, are being gradually overcome and carbonates are now being marketed as pure as 96/98 per cent., free from iron and lime; which, in connection with its reduced cost, is gradually extending its use. The claim for the use of the barium carbonate in glass is as a substitute for lead, lime or the alkalies, potash or soda, in that it imparts lustre, aids fusion, adds hardness, increases density, tends to reduce the liability of devitrification, and produces a glass that is very slightly affected by the atmosphere. Used as a substitute for lead, it is claimed that baryta-alkali glass melts as easily as lead-alkali glass, and that while baryta imparts density (like lead) it increases the hardness (like lime), without interfering with the density. In its use as a substitute for lime and alkali it hardens the product without retarding the fusion, and thus eliminates the liability of divitrification. But while it can be substituted in part, potash and soda cannot be entirely replaced by baryta. Approximately

90 parts precipitated barium carbonate replace 100 parts lead.
150 parts precipitated barium carbonate replace 100 parts potash.
200 parts precipitated barium carbonate replace 100 parts soda.
200 parts precipitated barium carbonate replace 100 parts lime.

Analytical Re-Actions.

Dissolve the carbonate in hydrochloric acid which forms barium chloride (BaC_2+2H_2O). It crystalizes in prismatic plates.

I. Add sulphuric acid, a white precipitate of barium sulphate ($BaSO_4$)

is produced immediately, even in dilute solutions. The precipitate is insoluble in all dilute acids.

II. Add calcium sulphate (plaster of paris). A white precipitate insoluble in all dilute acids is formed immediately.

III. Barium compounds color flame yellowish-green.

AUXILIARY ELEMENTS.

The accidental elements which usually discolor glass are iron and carbon, or carbonaceous matter. All glass exhibits a tendency to change color or fade, brought about by the general impurities present in materials of all kinds; as no material is absolutely pure. Iron and carbon are the most noxious elements, and are generally present in some proportion in nearly all materials.

Thus the fading of glass is a natural defect, and to counteract this and other defects so detrimental to that limpid whiteness of color sought in glass it is necessary to use certain substances whose counter effects neutralize and subdue, by means of oxidation, the effects of the impurity or discolorizer present. Generally speaking the decolorizing agents those which act by oxidizing the impurities.

Manganese, arsenic, antimony, potassium nitrate, nickel oxide, cobalt oxide and zaffre are all decolorizers. These ingredients are used in small quantities, as an excessive use brings about results other than those desired, by their becoming colorizers instead of decolorizers.

MANGANESE.

The use of manganese as a decolorizer has been known for several centuries, as Pliny wrote:

"To the materials of glass they begin to add the magnetic stone." Which has been determined as meaning manganese.

Manganese is found in nature either as di-oxide, Mn O^2 or as sesqui-oxide, Mn$_2$O$_2$, and is darker in color than iron, considerably harder and somewhat more easily oxidized. For well-defined compounds of manganese with oxygen are known in the separate state, viz:

Manganous oxide (monoxide or protoxide)	MnO
Manganuos, manganic oxide	Mno, $Mn_2O_2=Mn_3O_4$
Manganic oxide (sequi-oxide	Mn_2O_2
Manganese di-oxide (bin—per—or black oxide)	MnO_2

Manganese is a powerful oxidizing agent, on account of the facility with which it parts with a portion of its oxygen to any substance which has an affinity for it, and in the manufacture of glass without color mangenese is of vast importance as a decolorizer. It is one of the best and most effective agents in this capacity known.

The especial use of manganese in glass is to mask or neutralize the greenish color imparted to the glass by the protoxide of iron. Manganese imparts to glass a pink or red tint, which being complementary to green, neutralizes the color and permits the glass to transmit white light. Pellat refuted this theory, and claimed that the green tint of iron was not neutralized by the pink of manganese, by the pink being antagonistic to green, and thus subduing it; but by the iron taking another charge of oxygen from the manganese and becoming per-oxide of iron, and producing a reddish-yellow tint, while the protoxide produces a green tint. While it is asserted that decolorizing agents act by oxidizing the carbon, or protoxide of iron, such may be the case with other decolorizing agents, yet it is not absoultely true in regard to manganese. The excess of oxygen in manganese assists very materially in washing the impurities from the constituents, and aids in purifying color in this way also; but the greater richness of metallic manganese gives better results, especially if the ore is free from iron. An excessive use of manganese imparts an amethyst tint, and if the quantity is sufficient it will produce black. It is said that small quantities of nickel oxide and antimony act as efficacious decolorizers in place of manganese.

Nearly all manganese ores are peroxide ores, and the peroxide or di-oxide of Manganese, (MnO_2), composed of 63 parts of metallic manganese (Mn) and 37 parts of oxygen (O), is used extensively. Manganese oxide (Mn_2O_3), (sesqui-oxide), which is composed of 70 parts metallic manganese and 30 parts of oxygen, is also used. Also manganese protoxide (MnO), which is composed of 77.5 parts metallic manganese and 22.5 parts oxygen. Ninety per cent of an ore with a given test of Mn_2O_3 (sesqui) in as much as 100 per cent of an ore with same percentage of (MnO_2) (peroxide); which indicates a presence of 10 per cent more metallic manganese in the sesqui-oxide than in the peroxide or di-oxide.

One hundred parts per oxide (MnO_2) evolve 18½ parts of oxygen. It appears that the use of manganese is being largely abandoned in European factories, especially in window glass. Mr. Thomas Gaffield, of Boston, Mass., by a series of very ingenious experiments, demonstrated that under the action of air and sunlight, window glass containing manganese acquired first a yellowish color, and under continued action gradually assumed a violet tint; density of the color being proportionate with the amount of manganese present. While perhaps this demonstrates that manganese is not permanent as a decolorizer, yet the presence of iron in the glass may have considerable effect in this reaction, by the first reaction consisting of the higher oxidation of the iron producing a yellowish color, and the continued action of the elements oxidizing the manganous oxide, producing a delicate violet color, which, blending with the yellow, results in red. However, this applies principally to the use of manganese in window glass, and the purity of materials at the present day obviates the use of manganese in any large quantity.

Analytical Re-Actions.

I. Any compound of manganese heated on platinum foil with a mixture of carbonate of soda and nitrate, forms a bluish green mass; giving a green solution in water, which turns red on the addition of an acid.

II. Manganese compounds fused with borax on a platinum wire, give a violet color to the borax bead.

Arsenic.

Arsenic is obtained by roasting ores containing it. Such ores are heated in a current of air in furnaces having long chimneys, flues, or chambers, when the arsenic is converted into arsenous oxide, which is volatilized at that temperature, and as it passes off it is condensed and attaches itself to the walls of the chamber or flue. This is taken off and purified by a second sublimation when it forms the well known poison called arsenous oxide (As_2O_3), or white arsenic.

Arsenic is used in glass as a decolorizer, or purifier, but where manganese acts on the effects of the iron present, and is termed "the great decolorizer of glass;" arsenic acts principallly on the carbonaceous impurities present and is termed "the great decarbonizer of glass." In small quantities it promotes fusion, and decomposition of the other materials, and facilitates the dissipation of carbonaceous impurities not otherwise disposed of, eliminating them as carbonic acid gas, as arsenic when exposed in small quantities to intense heat is decomposed, owing to the vaporization of the metal; the oxygen is then available for cleansing purposes. An excess of arsenic, however, will produce a very objectionable "milkiness" of color in the glass, which age increases.

Arsenous acid, arsenic acid, and their salts exert their influence at a temperature above the fusing point and are volatilized.

Analytical Re-Actions.

I. Heat any arsenic compound after being mixed with some charcoal and dry potassium carbonate, in a very narrow test tube (or better, in a drawn out glass tube having a small bulb on the end), the arsenic is decomposed, and the metallic arsenic deposited as a metallic ring in the upper part of the contraction.

II. Heat arsenous acid upon a piece of charcoal by means of a blowpipe. A characteristic odor of garlic is preceptible.

NOTE—For years it has been a common custom in the glass trade to keep a large supply of arsenic in the manager's office or a place much frequented. The poisonous fumes from the chemical permeate the atmosphere and have been directly accountable for the death, or ruined health, of many managers. Don't keep arsenic in a frequented place.

Antimony.

Antimony is found in nature chiefly as the trisulphide (Sb_2S_3), an ore which is known as black antimony, crude antimony, or stibnite, and the oxides are obtained by roasting the sulphides. The metal is obtained by reducing the oxides by charcoal. Antimony is a brittle, bluish white metal, having a crystalline structure.

The introduction of antimony as an ingredient of glass has occurred in recent years, and it may be termed a "brightener," and is generally used as a substitute for arsenic, but not in conjunction with arsenic. Used in small quantities antimony promotes fusion, and aids in the elimination of impurities, performing the functions of arsenic. Used in excess, however, its effects are deleterious, as it destroys the nature of the glass. As a substitute for arsenic its proportionate use is about three-quarters to one.

Antimony is commercially obtainable as:

Ore, powdered	90/92%
Oxide	99%

The so-called "needle" antimony, and metallic powdered.

Analytical Re-Actions.

Boil a piece of metallic copper in a solution of antimonous chloride—obtained by boiling the native sulphide with hydrochloric acid. A black deposit of antimony is formed upon the copper. By heating the latter in a narrow test tube, the antimony is volatilized and deposited as a white incrustation of antimonous oxide upon the glass.

Cobalt. Zaffre. Nickel.

These oxides and their smalts are used in quantities of a few ounces each in lime and other flint "batches," as color neutralizing agents.

Smalt is an enamel, or glass colored with cobalt and powdered, and is generally used in connection with manganese, as a decolorizer.

Oxide of nickel is a black powder, and in its native state is nearly always found in connection with cobalt. The nickelous oxide, which contains less oxygen than the oxide, is dull green in color. Both are effective as decolrizers, and impart to potash glass a bluish tint, and to soda glass a hyacinth tint; used in excess they impart a violet tint. The tints imparted by nickel are constant.

Bone Ash. Calcium Phosphate.

Bones contain about 30 per cent of organic matter, and about 70 per cent of inorganic, most of which is tri-calcium phosphate. When bones are burned until all of the organic matter has been destroyed and volatilized, the resulting product is bone-ash. Bone-ash is used principally in the manufacture of opal glass, but the addition of a small quantity to a lime batch, assists in dispersing the impurities, and is recommended as a remedy for "cordy" glass. Avoid its excessive use in this capacity, as its tendency is to make the glass brittle and hard to fuse.

Iron.

So much has been said as to the effects of iron in glass, that but little more is necessary to be said at this particular place; except that traces of it are present in many raw materials; as sand, sodium sulphate, lime, baryta, etc., and as its effect is to impart a greenish tint to glass, where color is an object this tint must be neutralized or subdued by the action of decolorizing agents.

Alumina. Al_2O_3.

(Clay, Loam, Etc.)

In alumina the glassmaker has to deal with a material which is seldom purposely introduced into the "batch," but is always present as an accidental impurity, either in the materials, or brought by the action of the alkali on the walls of the pots, or furnace. It has the effect of rendering the glass less transparent (see opal), and in glass where brilliance and transparency are desired its presence in excessive amount must be avoided. Excess of alumina renders glass liable to devitrification.

Cullet.

(Broken, or Waste Glass.)

The use of cullet carries with it as much importance as any other material entering the composition of glass; as where the homogeneousness of the product is desirable, the use of cullet should be guarded. In truth glass made from fresh "batch," with a very small quantity of cullet, is much stronger and better adapted to the use of the finer grades of glass, especially that intended for beer, soda and other bottles which are subjected to high pressures.

Glass by being remelted loses strength, resistance and vitality, so to speak. Cullet is more fusible than raw materials, hence it aids fusion, and when properly disseminated throughout the "batch" in a uniform manner, it keeps the materials open, permitting the better escape of gases, and transmission of heat through the mass. Cullet should be carefully cleaned, especially if it is "chest" cullet—to which particles of iron adhere—as the effects of iron have been fully explained. It is best cleaned by keeping it immersed in a bath of dilute sulphuric acid to a temperature of about 180° F, for about twenty-four hours; which removes the iron. It should be then thoroughly washed.

Cullet should always be as near the nature of that of which it is to become a part, as possible; otherwise the product will be stratified and lumpy. It should be pulverized, as large lumps are not properly disintegrated by the action of the fluxes, and a lack of homogeneousness is the result. When cullet is introduced in proportionate, well regulated and prepared quantities, it aids fusion; prevents an undue volatilization of the alkalies, and produces a uniform product. Used in excess, however, it makes glass lose strength, become very brittle, lose firmness, elasticity and resistance.

Ordinary practice suggests a proportionate use of about one part of cullet to three parts of sand.

NOTE—Such materials as manganese, antimony, bone-ash, cobalt, etc., which exert a coloring influence, will be found more fully exemplified elsewhere. (See colored glass.)

ANALYSIS OF GLASS.

Kinds of Glass.	Analysts.	Silica.	Soda.	Potash.	Lime.	Lead	Magnesia.	Manganese.	Sesqui oxide of iron.	Alumina
Ancient glass.										
Egyptian tubes, colorless.	Benrath	72.3	20.8	.....	5.2	......	......	......	0.5	1.2
Roman urn............	"	70.3	21.9	.....	3.0	.....	0.3	0.9	1.9	1.6
Glass, Temple of Jerusalem	Campbell	69.3	13.8	1.5	8.5	......	0.5	......	2.0	3.3
Roman bottle...........	Benrath	70.7	17.5	.....	8.4	......	......	......	1.2	2.2
Tear bottle (brown).....	"	69.5	16.0	.....	8.4	......	......	2.3	1.5	2.2
St. Gobain plate glass ..	Peligot	73.0	11.50	.....	15.50	.....	.....	.....	.....	.....
French plate glass.......	Dumas	75.90	17.50	......	3.80	.....	.....	.....	.....	2.80
Chance's English glass..	Benrath	70.71	13.25	.....	13.38	.....	.....	.....	.....	1.92
British plate glass.. ..	Mayer & Brazier	77.36	13.06	3.01	5.31	.....	.....	.....	0.91	trace
Belgian plate glass......	Benrath	73.31	13.00	.....	13.34	.....	.....	.....	.....	0.83
Venetian glass	Berthier	68.60	8.10	6.90	11.00	.....	2.10	0.10	0.20	1.20
French window glass....	Dumas	68.00	10.10	.....	14.30	.....	.....	.....	.....	7.60
English window glass....	"	69.00	11.10	......	12.50	.....	.....	.....	.....	7.40
Russian window glass....	Benrath	71.27	20.10	.....	8.14	.....	.....	.....	.....	1.98
French lime glass.......	Pelouse	72.10	12.40	.....	15.50	.....	.....	.....	.....	.....
Bohemian lime glass.....	Berthier	71.70	2.50	12.70	10.30	.....	0.20	.....	0.30	0.40
American lime glass.....	De Brunner	71.92	14.55	.....	5.14	.....	2.04	trace	trace	6.22
English lead glass.......	Faraday	51.93	.....	13.67	.....	.....	33.28	.....	.....	.....
French lead glass........	Salvetat	51.00	1.70	7.60	.....	.....	38.30	.....	.....	1.30
American lead glass.....	Fletcher	53.98	6.71	7.60	.....	29.78	.....	.....	.....	1.93
French bottle glass......	Berthier	60.00	3.10	.....	22.30	.....	.....	1.20	4.00	8.00
Bohemian bottle glass....	Maumene	58.40	9.90	1.80	18.60	.....	.....	.....	8.90	2.10
German botle glass......	Benrath	69.82	18.28	1.50	7.82	.....	.....	.....	.....	2.58
Russian bottle glass.....	"	65.77	11.75	.....	16.58	.....	.....	.....	.....	5.90

If we consult the preceding analyses of different glasses we cannot fail to note how closely allied are the formulas used by people ancient and modern; and of different countries far apart. Which demonstrates that in the production of glass, its constitution must approach something near a definite chemical compound.

Association of Materials.

The association of the various ingredients for glass is perfected by two separate and distinct processes, namely: That comprising the mechanical association, in the preparation of the "batch" (as the associated raw materials are called), and mixing; and that process comprising the chemical association, by process of fusion by heat, of the several mechanically associated materials into a distinct mass.

Preparation of the Batch, and Mixing.

(Mechanical or Preliminary Association.)

As stated above, the first efforts towards the association of materials for glass are in the preparation of the batch. In doing this, the product desired should be well in mind, to determine the foundation of silica; with sufficient base to give it the required support, a proper proportion of fluxing agents, and ample colorizers, or decolorizers, and all accessories necessary to produce the glass required.

Under their respective headings we have endeavored to illustrate the general and special actions of the different materials entering into the composition of glass. It is impossible to lay down any definite proportion of materials for the different glasses, as glass is by no means a definite compound when made. The batches not only differ for the several kinds of glass, but different makers of the same kinds use the materials in widely varying proportions. Besides, irregularity of materials, and of furnace temperature, affect the composition. Careful calculation is always necessary to insure uniformity of result; and a glassmaker must not run away with the idea that a formula once established is always infallible.

It is important to remember that silica is the foundation of all commercial glass, and that the simplest compounded, hardest glasses, are cheaper than the softer glasses, and those rich in alkali, but are more difficult of fusion. Also that glass loses strength, resistance, tenacity and lustre, as the base or flux is increased; and that softness, hardness, tenacity, resistance to all deteriorating influences (as acids, or action of the elements), brilliance, uniformity, homogeneity, and color, are all features to be considered in the composition of the batch; and that the nature of the glass increases or diminishes as its composition varies from that required to form a definite chemical compound. All of which demonstrates the importance of a glassmaker possessing sufficient knowledge—technical and practical—to be able with well balanced judgment, to make a careful calculation as to what he wants, and how to get it.

To begin with, too much care cannot be exercised in the mixing room; even in the preparation of the simplest batches. All ingredients should be carefully weighed and sieved. All guess work should be strictly forbidden. The precepts of cleanliness should be rigidly enforced. Indifferent, careless workmen should not be tolerated. Two things especially important in the preparation of the batch are: First—That of having all materials reduced to a pulverized condition. Second—That of securing a thorough admixture of the batch. The importance of these features is obvious to the least intelgent mind. By reducing all particles to their finest possible condition while in a raw state, a closer mechanical association is affected, and they expose more surface to all reducing influences; effecting an earlier fusion of particles, and a closer combination results. A thorough admixture of materials is necessary so that in the chemical association each particle of sand may find its corresponding portion of alkali, oxide, etc., as may be required to insure homogeneity and uniformity. For the purpose of securing thorough and uniform mixing, the use of machinery is advised. A machine is tireless, and with proper attention, gives a definite result day by day. It is impossible to obtain workmen mixing by the time-honored hand and shovel process, who do not at times become careless and indifferent. The results of such indifference are always conspicuous, and many of the faults and defects of glass can be traced directly to it.

While most materials are now furnished in a finely pulverized condition, yet each material should be carefully sieved to remove all possibility of large lumps of soda, lime, etc., being incorporated in the batch, and from time to time should be tested for purity and regularity. Vigilance and watchfulness should never be relaxed in the mixing room. The use of the best materials obtainable is advised. While perhaps the first cost may be greater, yet they are economical in the end. Of course "the end may justify the means," but upon the whole, poor materials are expensive at any price. Good materials are readily available, and in dealing with such, calculations can be made to a close certainty, so far as materials go. It should also be remembered that pots and furnaces cannot be adapted to suit the mixture; the mixture must be adapted to suit them.

The Melt.

(Chemical Association.)

After the materials have been thoroughly incorporated mechanically, they are "filled in" (charged) the pots or tank for the purpose of completing the association. This constitutes the chemical association, and is comprised of two parts, viz: Melting or fusion; and "fining" (refining), and "standing off."

During the period in which barilla, kelp and other crude forms of alkali were in use, the batch was subjected to a process preliminary to melting termed "fritting." This was a perheating for the purpose of effecting partial decomposition, removing a moisture, and burning off any carbonaceous impurities; and was accomplished under the heat of a reverberatory furnace termed a "calcar arch," the residue being termed "frit." But the adoption of alkali prepared from salt has caused this process to be entirely abandoned. While perhaps in some instances it commends itself; yet generally speaking it is unnecessary.

As the raw materials in melting lose bulk, sufficient batch cannot be charged at one time. The pots are first filled to their capacity with raw materials, which are allowed to partially melt, and in doing so they reduce their aggregated bulk, and sink in the pot, leaving room for additional filling, which is introduced at stated intervals. Generally one such refilling called "topping out," is sufficient and is introduced about ten or twelve hours after the first filling. It is important to allow the first filling time to reach a state of fluidity before introducing any additional raw material. This avoids any interference with the first, or bottom filling; and allows the free escape of all gases which would be partially prevented by the batch becoming fluid on the top first, and enveloping the material in the bottom with a fluid sheet; (this is more especially the case with open pots), besides, when the bottom or first filling is reduced to fluidity first, it facilitates the fusion of any additional filling, and enhances the quality of the product.

So much, indeed, depends upon the melt, that no pot or furnace should be filled with batch until the temperature to which it is exposed is sufficiently high to immediately reduce, and melt the materials to a condition of fluidity without any interference. This insures a perfect combination and association of all materials, by allowing the molecules of all substances to properly disintegrate and combine into molecules of a new substance with a definite chemical equivalent. The calculations relative to the constituents of the batch are based upon the above; assuming that disintegration will ensue, affinity assert itself, volatility cease, and regeneration be complete, at certain calculated periods.

If after a pot has been "worked out," or after pot-setting, and the pot, or pots, are chilled, or the furnace is cold--and such is generally the case—it is inadvisable to "fill in" with cold batch until the temperature has been raised to a proper degree. It is better by far to "set up" stoppers, and wait an hour if necessary, as there is really no time lost in the melt by so doing. If the pot is hot the melt begins immediately, and goes forward continuously. If the pot is cold the batch does not begin to melt until the pot gets thoroughly heated, because batch is a very poor conductor of heat; besides the introduction of cold materials retards the absorption of heat by the pot, and encourages a "top melt." Again, the introduction of cold material does not exert the injurious effects upon a thoroughly heated pot that it does upon one that is chilled. If the temperature is sufficiently high, the pots properly heated, and the action continuous, the fusion of the batch proceeds from the bottom up; from the sides centerward; and to a small extent from the top downward, which is demonstrated by the cone-like lump which floats in the semi-fluid mass, and is the last of the raw material to disappear.

As the fusion continues, all moisture is evaporated, disintegration ensues, gases and acids develop and exude, and in their evolutions carry off all impurities (a portion of which are deposited on the surface of the glass). These gases answer the purpose of stirring the semi-fluid mass, and generate an agitation of the particles as the least refractory materials are reduced, while the then fluid fluxes slowly envelop and reduce the more refractory materials, until a condition of fluidity of the entire batch is reached. As remarked above, if this is a continuous process the product will be homogeneous and even tempered; but if the temperature falls below a point sufficient to properly continue the fusion and the process is interrupted, the agitation ceases—leaving in suspension a part or all of the partially disengaged impurities, the removal of which requires a renewed agitation, which is much harder to generate by a simple increase of temperature, as a portion of the materials containing the necessary gases have been volatilized. A foreign substance must be introduced to generate new gases, and cause a forcible expulsion. Deep insertion of arsenous acid, a potato, an apple, or stirring with a stick of green wood, are remedies sometimes resorted to. (These remedies are very often used for the removal of the pink tint, or "high color," imparted by excess of manganese). By closing up the pot after introducing the agent, the renewed agitation and consequent escape of gases, washes out a portion of the color or impurities.

The worst feature of a slow melt at an insufficient temperature is that the volatile ingredients of the batch escape at a lower temperature than that which is necessary to reduce the silica by a uniform attack of solvents, by which (alkaline silcates meltng at a temperature insufficient to fuse the silica, and more refractory silicates) the glass produced assumes partially a crystalline structure. Besides the melt proceeds principally from the top, and as explained above, envelops the lower portions with a fluid covering which retards the escape of the impurities, and develops non-uniformity, devitrification, foaming, stones, cords, bad color, and general indifference. "High color," especially, is imparted by the heat of the furnace being insufficient to reduce the manganese in proportion to the more fusible ingredients.

There results from the process of melting a considerable difference in weight between the raw materials and the product glass. This loss is occasioned by the disengagement of gases (other than oxygen, though this is expelled to a certain extent). In describing the different raw materials we have attempted to give an approximate estimate of the loss of some of them, but there is an estimated general loss of about one-sixth part of the total, including transfer of materials from the mixing room to the furnace, "filling in," and "working out," which also includes the loss by volatilization. This estimate is not definite, however, as glassmakers differ on the subject.

The batch and general conditions must be regulated to suit the furnace and pots, as the time consumed in melting varies under the conditions of the furnace, pots and fuel, and it is impossible to give more than a general process idea. A small pot melts quicker than a large one; likewise gas fuel will produce a better result than coal fuel; and coal is better than wood.

The melting process proper ceases when the materials have reached a condition of fluidity. The metal—as it is called—is yet full of seeds, bubbles, and such impurities as do not fuse, and must be driven off. The process called fining consists of freeing the glass from these imperfections, and such as are infusible rise to the surface of the glass. Fining (termed by the Germans Heissschuren) is an abbreviation of re-fining, and means purification. At this particular period the temperature of the furnace must be high as possible, in order that the glass may become very fluid; which aids in freeing the infinitesimal seeds, bubbles and impurities (estimated temperature 3,200°—3,600° F.) The time occupied by this process should not be too long, as a slow "plaining" generally results from insufficient heat, which means a lack of fluidity, and the bubbles, seeds, etc., cannot force their way out, which leaves a certain portion disseminated throughout the mass, while had the temperature been sufficiently high, and the glass very fluid, they would have risen to the surface; the gases would have escaped, and the heavier impurities be available for removal. Owing to a certain amount of volatilization of potash and soda, at the higher temperature necessary, more of these ingredients are introduced in the batch than are contained in the glass.

When the glass is entirely "plain"—and the fining process should not be interrupted until it is entirely so—and it is desired to "work" it; it must be reduced from the state of fluidity to that of viscosity. This process is called "cold-stoking," or "standing off," (termed by the Germans, Kaltschuren). It was the custom to bring about this result by lowering the temperature of the furnace. But in the introduction of covered pots, and the cold air blast, obviate the necessity of reducing the furnace temperature, and make it possible to work from as many pots as is desired, while the temperature of the furnace is continued at its maximum, and the balance of the pots continue to melt. This process of "standing off" has much bearing upon the general result, and must be accomplished carefully, inasmuch as immediately after a pot is opened the glass is in a spongy condition, with its surface generally full of impurities. By reducing the temperature gradually, the glass settles and solidifies in a uniform measure, and allows the impurities to collect in a manner that permits of their removal by "skimming."

But if the reduction of the temperature is forced, its surface becomes chilled immediately and the impurities remain in suspension, so to speak.

and not available for removal. If a pot ''comes around'' slowly, give it time to refine, let it settle and solidify, then reduce the temperature gradually, and it will be productive of a far better result than if it is forced. Always keep in mind that glass made by a slow melt contains inherent properties of devitrification which require but little to fully develop them. The use of water in cooling glass should be avoided as much as possible, and never be used in excess, as it destroys the nature of the glass by making it less tenacious and brittle, besides exerting an injurious effect upon the pots.

FAULTS IN THE GLASS.

Faults in the glass are directly or indirectly traceable to somebody or something. Impure materials, improper proportions, indifferent mixing, or insufficient heat to properly melt and ''fine,'' will individually or severally produce faults in the glass, and will incriminate the buyer, metalmaker, mixer or teazer. Intelligent inquiry will generally fasten the fault to its proper source, when the best remedy for the disease is to remove the cause.

In making glass it is always advisable to anticipate the result, and exercise proper and timely precautions, by wise forethought and scrupulous attention to details, to prevent any development which may possibly arise to interfere with the result.

One of the most prominent faults produced in making glass is the substance ''glass gall'' (salt water) (sandiver). This common impurity is more or less produced with all glass, and it is a general error to suppose that it is entirely a by-product of salt-cake, or that it occurs entirely in sulphate of soda, or salt-cake glass, as fair grades of soda ash have been found to contain as much eight to ten per cent of sulphate of soda, which by improper mixing and fusion readily develops ''glass gall.'' Girardin by analysis defines the constituent of ''glass gall'' in different glasses as follows:

	Window glass.	White hollow ware.	Bottle glass.
Water absorbed from atmosphere	1.65	0.10	1.00
Sodium sulphate	83.30	90.51	55.92
Calcium sulphate	10.35	6.00	25.00
Sodium chloride	1.43	0.04	0.20
Glass sand, alumina, phos. of calcium	3.35	3.30	7.77

Which demonstrates that it consists of non-fused particles of the batch, as chloride of potassium, sulphates of sodium and calcium, common salt, etc. As its specific gravity is less than that of glass, it usually rises to the surface of the metal, if the glass is properly melted and ''fined.'' It may be well to repeat, that these impurities represent a certain portion of the denser matter which the temperature has not been high enough to decompose, and when they become congregated, they form a dumpy, tenacious substance which when the fining process is interrupted, remains disseminated in suspension throughout the melted metal, where it is held in partial solution and impairs the clearness and transparency of the glass by its sub-division into white blotches and spots.

As to remedies for this impurity, a specific one is to remove the cause, by the use of pure and proper materials, in just proportion carefully mixed. However, it is impossible to entirely eliminate it in certain glasses. The most available remedy is to maintain a temperature sufficiently high in the furnace to allow the glass to become very fluid, in which condition the chlorides, sulphates, etc. (which melt without mixing with the glass and must be expelled or decompose) being lighter than the glass, escape or are readily driven to the surface, where they can be burned off by the use of moistened sawdust, pulverized coal, charcoal, etc. Or if allowed time, will accumulate in lumps and may be skimmed off. As sulphate of soda is the greatest generator of ''glass gall,'' carbon in some form must be introduced in the batch with it. Carbon facilitates the decomposition of the sulphate, and lessens the production of ''glass gall.'' Anything which generates a violent agitation of the melted mass is efficacious in removing ''glass gall''—as deep insertion of arsenic, potato, etc., and closing the pot for a period.

Another fault attributed to the melt is that of ''foaming.'' As a rule ''foaming'' is the result of insufficient heat to properly melt the materials. As has been already explained, the fusion of the batch in melting should proceed from the sides centerward, from the bottom upward, and never from the top downward. This insures uniformity of fusion, and allows all gases to escape in due proportion, and carry off their pro rata share of impurities. But if the fusion is effected by a cold melt, it is generally a ''top melt,'' which means that the batch begins to melt at the top first and encases the balance of the raw materials in the fluid sheet that retards the escape of generating gases, which by being thus confined develop sufficient power to throw off the more fluid and volatile salts that have fused at a temperature lower than that required to reduce the more refractory materials. This semi-fluid mass rises sponge-like and foams over the pot. This action of the gases by driving the more fluid and volatile matter to the surface, deprives the silica of a large portion of its flux, solvents and purifiers, besides allowing the more refractory substances to settle downward; the melt is prolonged and the quality of the glass impaired. To avoid ''foaming'' it is advisable to never introduce the raw batch into either pot or furnace until they are thoroughly heated, and the temperature high enough to effect a perfect and continuous fusion. In ''topping out'' always allow all prior fillings to reach a consistent condition of fluidity.

Other common faults in glass are stones, waves, cords and striae. These faults all arise—to a great extent—from causes in common. The hard whitish-colored particles, and the knotty wavy veined tenacious substance are too familiar to the glassmaker and worker to require any detailed description. Primarily these faults are the direct result of a lack of homogeneity in the melted glass—induced by one or all of the following conditions: improper materials, proportions, mixing, or fusion.

Perfect fusion is perhaps the most important preventive, as it imparts to the glass an even density, and eliminates by volatilization such impurities as are the cause of the faults, and serves to partially overcome and equalize the bad effects of impure materials, or imperfect proportions and mixing. Generally the cause and effects of devitrification will explain the presence of these faults. Perfect fusion eliminates devitrification. Large lumps of cullet glass inculcate waves and striae by not properly receiving the action of the fluxes, and while this cullet melts and becomes fluid, it does not disintegrate and incorporate itself uniformly with the other ingredients.

An excess of cullet is equally as productive of these faults, as glass, like other fusible substances, upon being remelted leaves a residue or "dross," and unless the temperature of the furnace is exceedingly high, and all agencies at work, this residue is not volatilized or expelled. Besides cullet being devoid of direct oxidizing agents, it is difficult to derive sufficient gases from the other materials to remove this excessive cullet impurity, and it remains disseminated throughout the metal. For these reasons a thorough admixture of cullet with the raw material is advised, in order to give it the greatest possible exposure to the direct action of the fluxes, etc. A cold furnace or pots, will produce, cords, stones, etc., abundantly (see Chemical Association), by imperfect fusion. Lack of sufficient oxidizing agents is as productive of these faults as an insufficient temperature to effect perfect fusion. Laxity in the mixture of materials of unequal density, especially lead, produces cords and striae (the density of lead glass is a source of constant trouble). The denser portions of the silicates have a tendency to separate themselves, producing stratification; hence it is very important to secure a thorough admixture of materials. The density of lead is far in excess of that of potash and the other alkaline bases.

The presence of alumina also inculcates cords, stones, etc. Alumina may be present in the batch purposely, or brought by accident from the walls of the pot. Alumina is very refractory and difficult to fuse. The incessant action of the fluxes (and other materials, especially cryolite), upon the walls of the pot or furnace, attacks them until they become corroded and full of indentations. The particles of clay and alumina thus torn down are deposited in the glass as stones, striae, etc.; besides portions of the raw materials collect in these small holes or indentations, and are not exposed to the direct action of the fluxes, which leaves them crude and semi-fused. As the glass is worked below these places, the semi-fluid substance they contain is drawn out and distributes itself over the surface of the glass. For this reason it is difficult to produce glass free from cords in an old or worn pot.

Glass remaining at the bottom of the pots any length of time, increases in specific gravity, and becomes infected with cords and stones, by the accumulation of the denser impurities being continually deposited therein. Glass should never be allowed to remain thus any length of time, but should be ladled into water, which in a measure disintegrates the mass into small particles, which present more surface to the action of the flux when next melted, and facilitates the removal of the faults.

The above presents in a general way, the principal agencies whereby these faults originate. The most effective remedy, as with other faults, is to remove the cause. But inasmuch as the causes are numerous, and one or more always present, an entire elimination is very difficult. Pure materials, well manipulated, and such remedies as are productive of violent agitation, are effective in expelling and destroying them. The use of rings or "floaters" in pots and furnaces is recommended, as they displace but little glass, and while they do not prevent these faults, they serve to keep them out of the way while better glass is being removed. But when the action of the fluxes begin to corrode them they must be replaced with new ones, else they become fault makers themselves. Bone ash, arsenic, antimony, or borax, incorporated in small quantities with the batch have been recommended to facilitate the removal of cords, stones, striae, etc., by oxidation.

FURNACES, FUELS, CLAYS AND POTS.

Furnaces.

While perhaps the construction and maintenance of furnaces and like appliances, does not as a rule, fall under the direct province of the glassmaker, yet there are but few processes connected with the manufacture of glass, which are not directly or indirectly dependent upon the influences of heat; and the various characteristics of glass—to say nothing of its formation—are so effectively modified by its influences, that heat, its generation, and application, requires more than a glassmaker's transient attention. In this connection the furnace performs an absolute and important part.

The word "furnace" is elastic, and can be properly applied to a number of varied structures contingent to the industry. But the categorical definition of a furnace is applied more directly to the structure in which the raw materials are fused by heat into glass, and is so considered. For obvious reasons we must eschew more or less, all data pertaining to the furnaces of the ancients, and confine the following to those of more modern times.

The modern glass-melting furnace is simply a modified form of the reverberatory furnace, which statement implies that the materials to be melted are exposed to the action of the flame, but not to the contact of the burning fuel. While various modifications exist, yet modern furnaces may be divided into two general classes, viz.: Pot furnaces and tank furnaces. Pot furnaces are constructed to assume different shapes, viz.: For window, plate, or bottle glass, they are built either square or oblong. For flint glass they are built round or oval. Tank furnaces are constructed to give either continuous or intermittent results without the use of pots, and may be of different shapes, but an oblong shape usually prevails. Both classes of furnaces are built to consume fuel by its direct introduction into the furnace, or by indirect combustion by effecting the generation of combustible gases in a separate apartment, and conducting them to the furnace proper for final and effective combustion.

The ordinary direct-fired furnace may be said to consist of two parts: The combustion chamber, and the draft passage or "cave." These two parts are separated by the grate, and "siege," or "bench." The grate may be round or square, dependent upon the shape of the furnace, and contains the fuel, which can be introduced from one or more openings termed "teaze-holes." The grate generally occupies the center of the furnace, being sunk below the "bench" a few feet, and is connected with the combustion chamber by a walled cavity termed the "eye," into which the fuel is placed. The "siege" constitutes the raised bench-like portion of the combustion chamber upon which the pots are placed. The "cave" is an arched passage beneath the furnace for the admission of air to the grate. Very frequently two caves are built, which cross at right angles beneath the grate, which facilitates the admission of air from all directions.

The number of pots in a furnace vary from four to eighteen, and are reached for working or charging by a small arched opening, or "working hole," situated directly over each pot; except in a flint furnace where covered pots are used, in which case the mouth of the pot is exposed on the outside of the furnace walls. The combustion chamber is surmounted by a low flattened arch for the purpose of reverberating the flame and compressing it to intensity. For this reason the arch should be as low and flat as possible. The flame after reverberating is led to the exterior by means of flues, or small chimneys, constructed in or against the sides of the furnace. In the style of furnace used for window, plate or bottle glass, frequently no flues are used, the products of combustion making their exit through the working holes; the prime object of flues being to draw the flame completely over and around the pots, and thus aid reverberation. Besides, a flint glass furnace has no other exit for the products of combustion than the flues supplied to each pot. As it is essential that all flues should be kept clean, provision is made for the purpose. It was frequently the custom in earlier days to construct a furnace with two arches, one above the other; the lower one constituted the reverberatory arch and the upper one the top of the furnace. The products of combustion congregated in the space between the arches and escaped through a common flue in the top one. This space between the arches was also used sometimes for numerous purposes requiring heat. Again, instead of the top arch, the outside walls of the furnace are continued in the form of a truncated cone, or open chimney. In other cases the flues discharged their contents into the glass-house itself.

In all cases a necessary draught is required to properly consume the fuel; hence different construction of furnace tops, or stacks, is necessary, according to fuel employed, draught being that action due to the difference in weight between the column of hot gases in the stack, and a column of air of equal height and area at the temperature of the atmosphere. Thus draught depends upon the difference in temperature of the gases within, and the air without, and the height of the stack. As we have remarked, different fuels require different draughts, and after a height sufficient to produce the required draught is obtained all additional height of stack is a waste of money. This general description is applicable more or less to all direct-fired furnaces. All efforts toward dimensions of furnaces are avoided here, as the variation is such as to exclude anything definite.

Gas furnaces consist of two principal parts, viz.: combustion chamber and producer. Tank furnaces are constructed along similar lines, inasmuch as gas is the most effective fuel, and is generally used, although other fuels, as oil, are used to some extent. The principle involved in a tank furnace is the entire abandonment of pots. But it is not our purpose to enter into any general discussion of the various tank furnaces, but to simply outline the more important principles involved.

Owing to the time occupied in melting the materials for glass under the pot system, various experiments were made towards effecting a plan to melt and blow continuously, without adding to the cost, or affecting the quality of the glass. M. Chamblant devised a pot with a crooked pipe. Bontemps also mentions a pot with a partition. Siemens devised a pot with three apartments, and by demonstrating the feasibility of melting and blowing continuously, these experiments led to the development of the continuous tank furnace. The principle of the tank as specified by Dr. Siemens in 1872, was a long tank about four feet deep, with a semi-circular end, and divided by two transverse floating bridges, into three apartments, viz.: melting, refining and working. In some instances the floating bridges are dispensed with, as the action of the heat and glass disintegrates and destroys them, and a refining vessel ring has been substituted opposite each working hole. This vessel gathers the melted glass at the lowest possible depth in the tank and raises it continuously to the surface, in a compartment prepared for the purpose, completely refined. These vessels vary in shape and style, and can be removed and replaced when worn. To obviate the action of the materials used in the production of glass upon the brick and clay construction, Dr. Siemens devised a series of air passages, which kept the glass chilled along the walls and bottom and protected the parts exposed.

There are many advantages resulting from the use of a continuous melting tank furnace; the principal reasons may be given as follows: Increased production, economy in working, durability of furnace, regularity of working, and improvement in quality of glass.

The success achieved by continuous melting tanks in making window glass led to successful efforts in the construction of small intermittent (commonly called "night melting" or "day") tanks. The greatest obstacle, however, has been the maintenance of color, caused by the glass melting principally from the top, leaving the bottom glass less fluid and more refractory. But the past decade has rapidly developed the intermittent tank, until at the present day a very fair grade of so-called flint glass is in many cases being produced. With these small tanks, gas fuel probably produces the best results, but oil is being introduced as a fuel, with a marked degree of success. Coal is not often used as a fuel by direct firing for the better grades of glass, but can be used in connection with super-heated air. One patent in this direction provides for the air being heated in a cast iron chamber by radiated heat from the fire-box, or furnace, and is then conveyed in pipes to a point where the flames pass over the "bridge" wall, where it combines with the gases from the coal, and facilitates combustion in a very effective manner. The products of combustion, after traveling the length of the melting compartment, pass off through a stack at the end of the tank.

In the construction of any furnace four general principles apply, viz.: Intensity of the heat obtainable; regularity in maintenance of this heat; durability of parts exposed thereto; and economy of fuel producing same. Upon the intensity of the heat depends the uniformity of the melt and homogenity of the glass. The regularity of the heat actuates those influences which determine the quality of the glass, as but slight variations of the temperature impair homogenity and produce stratification. The durability of the furnace depends upon the stability of materials and construction. Where the furnace contains open pots, or is a tank, and the interior of the furnace is exposed to the higher degrees of heat obtainable with gaseous fuel, clay brick, especially in the crown, are affected and the semi-fused matter drops into the glass, producing impurities. This defect is largely obviated by the use of brick and materials composed principally of silica, which are absolutely infusible if kept from contact with alkalies and other substances which would act as a flux. Economy of fuel is principally dependent upon the construction of the furnace and the methods of combustion.

While tank furnaces are gradually gaining favor, they have by no means replaced the pot furnace in glassmaking. Yet the direct-fired furnace is slowly giving place to modifications which propogate economy in construction, fuel and heat. The application of artificial gas as a fuel is one of the most important improvements in modern glassmaking. To say nothing of economy in fuel—and the possibility of the use of cheaper fuel—permitted by a gas furnace, the time of melting is reduced, production increased, and the product vastly improved.

The so-called "deep eye" furnaces are modifications of the direct coal fired furnace, but are constructed with a view to facilitate combustion by effectively combining air (generally superheated) with the gases arising from the fuel, at or near the point of entrance into the furnace or combustion chamber. This combination is generally effected by a series of small flues around the "eye" near the top.

The fact that combustion is facilitated by the introduction of superheated air with the gaseous matter imparted by coal, at or near the point of ignition, was successfully demonstrated by Dr. Siemens when he introduced his producer and regenerative process and the Siemens gas furnace was the first successful one used. In this, as in other forms of gas furnaces (except natural gas), the solid fuel is first converted into a combustible gas in a "producer" outside of the furnace, and then burned in connection with heated air. Dr. Siemens was the first to apply the regenerative system to the pot furnace, the principle and construction of which was changed only so far as was necessary to apply the regenerative principle. The novelty of the Siemens process consisted in taking up the heat usually wasted and utilizing it to raise the elements of combustion formed by the producer to a high degree of temperature before ignition, by heating the gas and air employed in separate regenerative chambers heated by waste heat from the flame. These "regenerators" comprised four chambers filled with fire brick, stacked loosely in checkerwork. The gas from the producer, passing through one chamber, and a current of air through another, meet and unite just before entering the furnace. These two chambers have been heated to a high temperature prior to the escape of waste gases through them; hence gases and air are brought to a high temperature during their passage through them, and readily ignite at their entrance to the furnace. The action is then reversed, and the gases and air pass through the second pair of chambers, while the waste gases reheat the first pair, and prepare them for again performing their functions when their turn comes. This alternation occurs about every twenty or thirty minutes.

The old style direct-fired furnace was a very simple affair. Ingram's furnace was intermediate between the direct-fired furnace and the gas furnace. Boetius' furnace was a forerunner of the Ingram furnace, and was perhaps the beginning of the resultant outcrop of "deep eye" furnaces. The so-called Gill furnace is an improvement upon the principle of the

Boetius furnace, and has flues arranged to convey the air to the combustible gases evolved from the fuel. Direct-fired furnaces can be remodeled to this style, which claims economy in construction, fuel and pots, and insures an intense heat. The Nicholson furnace is an improved form of a French furnace, but differs from the Siemens furnace in not having the alternate regenerators.

Innumerable improvements have been devised in furnace building in late years, a recent instance being a furnace patented in Germany, which provides for the special heating and regulation of the temperature at will for each single pot, by the burning gas entering the furnace at the center as in the old system. But for the uniform heating of the pots on all sides, or for the special heating of any single pot, there are additional gas channels provided, which are met by air channels shortly before their entrance into the interior of the furnace. These additional gas channels are fed from a joint channel, which runs from the producers along each side of the furnace, gas and air supply being regulated by slide valves.

Furnace construction in Germany and Belgium is far in advance of the art in our own country, and American furnace builders so far seem content in copying the approved models of European construction.

FUELS.

The fuel used in the early glass houses was wood, which was dried, or baked, until it was brown, to expel all moisture before using. Even in some countries at the present day wood, turf and peat are extensively used. The use of coal is by no means a recent invention, as it was in use during the time of Agricola. But the smoke and by-products of coal have always been a serious objection, especially where the materials to be melted are exposed to the direct action of the flame by contact, as in tanks or open pots. Hence for a time wood was preferred. Oven-burned coke has been largely used in England to an advantage, and was especially recommended in the manufacture of the finer glasses on account of its freedom from soot, smoke and by-products. In this country wood was used as late as 1865, but since that time coal has been used almost exclusively, until the discovery and application of natural gas as a fuel; but the gradual decline of this fuel has necessitated and developed other cheap fuels, as artificial or producer gas, oils, etc.

Fuels and their economic combustion constitute an important issue industrially, more especially in the manufacture of glass. This, and the efficacious application of the resultant heat, should be a thoroughly familiar subject to the practical glassmaker. Heat is obtained by the combustion of fuel. Every fuel—wood, coal, or gas, contains a certain number of heat units which are given out by combustion, and no more heat can be obtained from any given fuel than the number of heat units contained in it, which will be the same under all conditions, whether combustion is slow or rapid, or at a high or low temperature. A heat unit is reckoned by the amount of heat necessary to raise the temperature of a unit quantity of water one degree centigrade. This is taken as unity, and the amount of heat necessary to raise the temperature of a unit quantity or other substances one degree, is expressed in terms of the amount necessary to raise the temperature of water one degree. This relation is called the specific heat of a substance, thus—if the specific of water is 1 (one), alcohol only requires seven-tenths as much heat to raise its temperature one degree, hence it has a specific heat of 0.7.

The heat units set free by the combustion of a fuel are expended in two ways: First, by radiation, and being carried off by the hot gases passing up the stack. Second, absorbed by the surface to be heated. All things considered the loss by radiation is proportionate to the time occupied by combustion, hence it is economy to burn fuel quickly.

As a general fuel, coal probably takes precedence over all others. In burning one pound of the average dried coal there is consumed about 2.45 pounds of oxygen, and 10.7 pounds, or 140 cubic feet of air at 62° F, by which there is given off about 14,700 heat units. Coal may be arranged in five classes, viz.:

I. Anthracite, consisting almost entirely of free carbon.
II. Dry bituminous coal, containing 70 to 80 per cent carbon.
III. Bituminous coking coal, containing 50 to 60 per cent carbon.
IV. Long flaming or cannel coal, containing 70 to 85 per cent carbon.
V. Lignite or brown coal, containing 56 to 76 per cent carbon.

There are two conditions on which the economy of combustion of any fuel depends: The method of firing and the supply of air. Bear in mind the fact that the object is to set free the entire amount of heat available, and in such a manner that the surfaces to be heated will most readily absorb it. As oxygen is the chief supporter of all ordinary phenomena of combustion, the combustion of a substance consists in the addition of sufficient oxygen to oxidize the substance. A combustible requires in the first place, to be heated to a certain degree before it will attract and combine with the oxygen from the atmosphere with sufficient force to emit heat. But as the temperature is elevated by the continued absorption of oxygen, the combination of one portion of oxygen with the burning body causes the absorption of another. But different substances require different amounts of oxygen to oxidize them. Thus carbon requires two atoms of oxygen to one of carbon, and in burning any substance which is largely carbon, as coal, there must be an ample air supply from which sufficient oxygen can be extracted to completely consume the substance. Smoke is an evidence of incomplete combustion, but there may also be incomplete combustion when there is no smoke.

Two forms of carbon are found in coal, one fixed, and another in a volatile or gaseous state. The volatile carbon is generally combined with hydrogen, forming the so-called hydro-carbons, which are readily given off upon the application of heat to the coal, and unless these gases are thoroughly mixed with air, and kept with it at a high temperature they are not consumed and escape up the stack as smoke. This is illustrated when a fresh supply of coal is added to the fire. There must always be sufficient air present to properly combine with these gases, or their combustion is not complete. Further than this, where there is a lack of oxygen the carbon, only partially oxidized, passes off as vapor, which when it comes in contact with a cold surface, or air, is condensed and partially reduced, forming black smoke. A thick bed of fuel furnishes another cause for incomplete combustion by allowing the oxygen in the air as it passes through the heated fuel to combine with the carbon in unequal proportions. Ordinarily with sufficient air it is combined as one of carbon to two of oxygen (CO_2). But if it is required to pass through too much hot fuel it absorbs more carbon and becomes CO, and if the air is not sufficient to allow it to take up another portion of oxygen and become CO^2, it will escape imperfectly consumed, as the carbon is only half oxidized. The quantity of air required varies with the fuel, furnace and method of firing, and becomes less in proportion as the temperature of the firing and rate of combustion is increased. It may be well to mention that on account of the volatile matter which forms a part of some coals, provision should be made for the admission of air above the grates to aid in the consumption of the partially consumed gases given off by the coal.

One ton of Pittsburg coal contains about 10,000 cubic feet of gas, 12 to 14 gallons of tar, and about 1,350 pounds of fixed carbon, and the heat units contained in it equal the heat units in about 200 gallons of Lima oil.

The class of fuel always affects the design of the grate, as a clinkering coal, for instance, requires large air spaces; a small, dry coal, small air spaces. There are different methods of firing coal; as that of spreading—when the coal is spread over the entire grate surface at one firing, which permits the escape of all volatile gases until the entire mass is ignited, and the flames rise above the coal. Another method is that of coking, by laying a bed of coal where it will be allowed to coke, when, after coking, it is pushed forward, upon the bed of incandescent coals and another bed of "green" coal is put in its place. This method keeps the bed of fire on the grate bright and incandescent, and allows the volatile gases which the heat causes the "green" coal to give off, to be led over the incandescent mass and be thoroughly consumed. Bituminous coals whose fractures show whitish films or rusty stains should be avoided, as they indicate the presece of sulphur and pyrites in the coal.

We give herewith a table of some of the domestic coals:

State	County	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
Alabama	Barbour	2.50	31.50	63.07	2.17	1.02
Arkansas	Huntington ...	1.29	18.91	72.30	7.66	.72
Colorado	Boulder	2.80	36.30	37.10	23.80	......
Georgia	Dade	1.20	23.05	60.50	15.16	.84
Illinois	Clinton	14.64	30.71	51.99	5.64	.98
Indiana	Clay	2.80	34.92	60.47	1.80	.98
Iowa	Marion	7.08	37.84	32.47	22.59	......
Kentucky	Muhlenburg ...	5.33	33.65	54.25	4.95	1.95
Maryland	Allegany	1.09	17.30	73.10	7.74	.74
Missouri	Caldwell	5.06	34.24	47.69	13.01	......
Nebraska	Adams	.21	27.82	60.88	11.09	......
New Mexico.....	....	2.35	35.53	50.24	11.88	.61
Ohio	Belmont	......	35.20	64.80	......	......
Oregon	Coos	16.36	41.85	32.67	7.11	......
Pennsylvania ..	Allegheny	1.04	37.21	56.13	5.61	.98
Tennesse	Hamilton	2.74	26.50	67.80	3.68	.91
Texas	Tarrant	9.51	32.37	44.90	12.21	1.51
Utah	Emery	3.43	42.81	47.81	9.73	......
Virginia	Pocohontas.....	.57	21.19	74.71	3.53	.40
West Virginia.	New River....	.85	18.42	77.57	2.89	.26
Wyoming	Sheridan	6.04	42.37	35.57	16.02	......

Natural gas needs no process to make it merchantable or valuable as an industrial fuel. The calorific value of natural gas as compared to artificial gases is generally quite high, and bulk for bulk it is one-third greater than enriched water gas. By a series of tests, Prof. F. C. Phillips, of the Western University, Allegheny, Pa., determined the heat units in 1,000 cubic feet of average quality natural gas to be 1,164,030 (British heat units). The specific gravity of natural gas varies from 0.55 to 0.60, as compared to dry air at 60° F. The composition of nearly all natural gas closely resembles Marsh gas, CH_4, and 85 to 98 per cent of the whole is nearly equivalent to Methane, or Marsh gas (75 per cent of carbon and 25 per cent of hydrogen).

We give herewith two analyses of natural gas which will be sufficient to illustrate the general composition:

Analysis of Natural Gas From Pennsylvania:

Oxygen,	(O)..................	trace
Nitrogen,	(N)..................	9.54%
Carbon di-oxide,	(CO_2)..................	0.41%
Marsh gas,	(CH_4)..................	90.05%

Analysis of Natural Gas From Findlay, Ohio:

Hydrogen,	(H)..................	1.64%

Marsh gas,	(CH_4)	93.35%
Olefant gas,	(C_2H_6)	0.35%
Carbonic oxide,		0.41%
Carbonic acid,		0.25%
Nitrogen,		3.41%
Oxygen,		0.39%
Sulphureted Hydrogen,	(H_2S)	0.20%

The amount of air required to consume 1,000 cubic feet of natural gas is slightly less than 11,000 cubic feet, or about one part of gas to 11 parts of air; practically 1 to 10 gives good results. Natural gas is undoubtedly an ideal fuel, but, in most districts it is fast diminishing, and is either "gilt-edged" in price, or is so erratic and uncertain in its supply as to cause the manufacturer much annoyance and loss. Hence those who adopted it is a fuel, as well as those who have felt its influence in competition, have sought an economic fuel to replace it. The nearest approach to it as an industrial fuel is artificial gas, which for practical, economical results and stability has all its advantages, and without doubt "producer gas" generated from bituminous coal in any standard gas producer is beyond question the best form of fuel yet instituted in the glass industry, as the economy of fuel is not only great, but the heat produced is intense and shows a direct saving in fuel of never less than 30 per cent, and often as high as 75 per cent.

The principle applied to a producer is as follows: The fuel is supplied at intervals through charging boxes, and descends gradually on an inclined plane set at an inclination to suit the fuel, until it reaches an open grate formed of flat horizontal steps, where the fuel is converted into a combustible gas which passes off through an "up-take" to the furnace. The production of combustible gases varies with the admission of air, and the process of gasifying the fuel occurs by the fuel becoming heated as it descends, when the hydro-carbon gases, water, carbonic acid and ammonia are evolved, which leaves about 60 to 70 per cent of carbonaceous matter which is disposed of by the action of a current of air slowly entering through the grate, producing combustion in a regular manner upon the grate. Carbonic acid is a result, which passes through the incandescent fuel where it absorbs another equivalent of carbon and becomes carbonic oxide, which is a combustible gas, and is incorporated with the other combustible gases already evolved. Water is sometimes utilized by being brought to the foot of the grate, where it absorbs spare heat from the fire and ashes which converts it into steam, and as the steam passes through the incandescent fuel it is decomposed into its elements, after performing its useful function by disintegrating the clinkers.

For many years producer gas has been utilized as a fuel under the regenerative system of Dr. Siemens, but for a long time it was a question apart from economy whether it was possible to use producer gas direct, and some of our most learned theorists decided that its direct use was impracticable. But it has been practically demonstrated that it can be, and is used direct without any connection with the regenerative process in furnaces, glory-holes, lehrs, and even under the boiler for generating steam. There are a variety of producers, which are all, however, modifications of the same general principle, the prime object in all cases being to convert with the greatest economy, a given amount of fuel into combustible gases. Steam is sometimes used as an auxiliary agent, but where steam is used it is important to have the coking chamber of sufficient size to insure an economical conversion into gases, otherwise the application of steam becomes void as an improvement, as by some small producers not over 60 per cent of the coal is converted into combustible gases. Steam and air forced through a grate become converted into fixed gases when compelled to pass through a large body of incandescent coal in a coked condition, and as these gases (CO and H) come in contact with the fresh fuel on top of the coked portion, they drive off the volatile matter contained in the coal which mixes with the fixed gases generated by the coke. As has been said above, in some producers water is used as a seal around the base, which minimizes the loss of heat in the ashes by radiation, escape of heat and air up the sides, equalizes the draught, and utilizes the waste heat from the ashes in the generation of a steam vapor which rises through the fuel and softens the ash, disintegrates and prevents clinkers, and with its hydrogen and oxygen, after gasification, enriches the gas.

During the past decade various schemes for utilizing certain oils as fuel have been tried with indifferent success, from the fact that most of them were with crude petroleum, and required a more or less complicated system of burners for generating gases, or producing combustion in some other complicated manner. One of the most successful methods introduced is to use the cheap heavy oil of 34 to 40 specific gravity, which is more or less a refinery by-product. This oil generates immense heat energy, and can be successfully and economically burned in connection with an air pressure of from 2 to 7 ounces per square inch. This air meets the flow of the oil at the end of the burner and completely atomizes it in a spray, furnishing just sufficient oxygen to perfect combustion. As a clean fuel, oil highly recommends itself, and petroleum residues have a high calorific value by being rich in carbon and of perfect safety. Their fire test is at least 200° F, and about 65 per cent of their heat is effective as against 60 per cent of coal.

Benzine is another oil fuel used largely in certain branches of the glass industry. While perhaps the first cost makes benzine a trifle expensive, yet it is especially adapted as a fuel for "glory holes," particularly in the manufacture of bottles. It can be burned very successfully by means of a suitable simple burner, producing an effective, regular, uniform heat, and requires but little attention.

FIRE CLAYS.

Their Preparation, Use for Pots, Etc.

The clay adapted to use for pots should be as pure as possible and very refractory, breaking with a clear, smooth, bright fracture, unctuous to the touch, free from lime and sulphide of calcium, the least iron possible being most desirable. Heretofore the German clays have been largely employed in this country, as the American clay when first used did not give the satisfaction that its analysis would indicate, but skill in its preparation has demonstrated its value and it is rapidly taking the place of the imported clays. There are large deposits of excellent pot clays in many localities in this country, the chief supply being derived, however, from Pennsylvania, Missouri and New Jersey. Missouri plastic clays are probably the most important of American clays. They occur geologically in the coal measures under the seams of coal, and show a shrinkage of from two to nine per cent in burning. Their fusibility ranges from 2500° to 2800°. Missouri clay is purer than the German clay, and is more refractory, but not as dense, and it is found by experience that it will stand a more intense heat than any other clay, but German clay resists the action of the fluxes better. Hence the German and American clays are frequently mixed to overcome as much as possible, the two difficulties.

After clay is mined it is exposed to the disintegrating action of the weather for a considerable period. While the actual effects of the weather are not definitely understood, yet the plasticity of fire clay is considerably augmented by the process of "weathering," as it is known that organic matter is eliminated by oxidation, and the particles of clay disintegrated by moisture and frost. After being weathered sufficiently, it must be dried well and stored in a dry place. When it is perfectly dry the outside crust must be removed, and the lumps picked to pieces, and all substances, as pyrites, or bluish portions removed. The clay must then be ground, and carefully sieved, to eliminate all impurities, and the greatest care and cleanliness exercised in its manipulation, as even the fibre off a sack would spoil a pot.

Regarding the selection and adaptability of a clay, Mr. H. J. Powell gives the theoretical composition of pure fire clay as: Al_2O_3, $2SiO_3$, $2H_2O$. In selecting clays for exposure to fire it must be understood that infusibility, stability and plasticity are important qualities. The infusibility increases with an increased proportion of silica, augmented by alumina, and diminishes with the increased proportion of the other constituents. Or in other words, as the fusible constituents rise above a certain proportion, the clay can be fused into glass. The color of unburned clay is hardly a criterion as to the quality, as it is often deceptive. Lime and magnesia oxides, especially in increased proportion, impart a whiteness in color, and again the color of the oxide of iron is often concealed in unburned clay by the presence of organic matter, but is revealed by the action of heat. The investigation of a clay must include an examination of its physical properties, the percentage of clay base, the determination of plasticity, amount of water required to make a plastic mass, the tensile strength, shrinkage in drying and burning, vitrification, viscosity, etc., etc.. It is assumed that plasticity is due to the interlocking of the particles, and that its tensile strength when dry, is an index of its plasticity when wet. That plasticity varies with the size of the grains, is demonstrated by the following series of tests:

Test of tensile strength of clays in different grades of fineness.

Size of mesh.	Per cent water used.	Per cent. Tensile strength Maximum.	Average.	Plasticity ratio
20—	18.0	190	142	100
20—40	19.3	196	182	103
40—50	20.4	182	172	96
70—100	17.5	183	176	96
100 and smaller	78.6	143	135	71

As a simple and practical test for fire clay, Mr. H. J. Powell, recommends the formation of the sample into brick; then break the brick into two pieces, and expose one piece to any required heat to be burnt, while the perature; the resistance to chemical influences; and last, the proper proquality the burnt piece will be white in color, and the fractured ends of the burnt and unburned pieces will fit exactly.

The simple use of a good quality of fire clay does not insure the quality of the pots made from it, as certain conditions are involved which must always be considered, viz.: The preparation of the clay, and the proportion of raw and burnt materials in the mixture; the judicious manipulation of the pot-maker; the method and manner of drying the pot; its annealing; the temperature of the furnace; and the kind of glass to be melted. Possibly no two manufacturers prefer the same clay, or use the same proportion in their mixture, and when a manufacturer establishes a standard, there is rarely any deviation therefrom, for the obvious reason that experiments with pots are expensive. But where the value of a good clay is known, the result is, under proper conditions, as a rule good.

There are several things necessary to be ascertained regarding the serviceability of clays, before any definite result can be anticipated, namely: The ratio of contraction by air and fire; the resistance to change in temperature; the resistance of chemical influences; and last, the proper proportion in mixture with other ingredients. These features can only be ascertained by test, analysis and synthesis; analysis to determine the elements of the original compound, and to ascertain those constituents requisite, that by synthesis, a compound definite in results may be formed. The analysis of a clay does not present any definite factors, but rather a maze of elements which must be separated into the anatomy of a structure; for instance, the percentage of the plastic elements—the true clay substance—must be determined, this represents the muscle; the percentage of fusible material which melts when exposed to heat, and binds the particles together, this represents the binding tissue; and then the percentage of quartz, or flint, the skeleton. This resolves itslef into simple factors, by which a pot-maker can determine whether the skeleton has strength, the binding tissue is sufficient, the plasticity—or muscle—excessive, or insufficient, and thus he can readily determine the character of the mixture he will have to make.

Regarding the mixture of clays, it is important that the raw clay be finely ground and sieved to insure plasticity, as pots made from plastic clay are quite as durable, and resist chemical action; but the more plastic the clay, the more it is exposed to contraction. Hence to obviate this, the plasticity or ''fatness'' of the clay is made less by the addition of coarser-grained burnt clay powder (chamotte), or ground pot scrap. These materials are called ''leaners,'' and serve to bind the clay and heighten the resistance to sudden changes in temperature, by facilitating the escape of the water contained in the clay, during the drying process, as well as that of the chemically combined water, during the annealing and burning of the pots. In making this mixture for pots, it is customary to use either eight parts, by volume, of finely ground burnt clay, and seven parts of pulverized raw clay, or four parts of finely ground burnt clay, three parts of finely ground pot-scrap, and six parts of pulverized raw clay. But the proportion in which clays are mixed is not the same in all glass houses, as it is always to be considered whether a ''fat,'' or meagre composition is desired. Many pot-makers consider it inadvisable to mix in pot shell, or different clays, using the same grade of clay for raw, or burnt portions. When raw clay is used for the production of burnt clay powder, it is formed into cakes several inches thick, which are stacked loosely in an oven, allowing for the free circulation of heat, and uniformly roasted to remove all organic matter, using great care in the regulation of the heat to prevent glazing on the clay. These cakes are then ground to a powder, as the size of the grain is very important, for plasticity and density increase with fineness, and contraction is proportionate and increases with density. Hence, while the finely powdered material improves the value of the pot in one direction, it is detrimental in another, as it increases the sensitiveness of the product to any change in temperature. This defect is partially avoided by using the ''leaner,'' or chamotte, in a proportion of one-half coarse-grained, and the other half powdered. This powder fills out the spaces between the larger grains, and acts as a binding agent, and supports resistance to change in temperature. While contraction is counteracted by the proportionate use of burnt clay, yet loss of plasticity and strength of materials vary accordingly, and, as a thin walled pot is efficient in melting glass, it is not wise to sacrifice plasticity to prevent contraction; besides the pot is exposed to strong internal pressure, and disintegrating agencies requiring resistance, hence strength is essential, and the injurious effects of contraction can be almost entirely eliminated by prudence and care in drying and burning the pots. In materials for furnace construction, where contraction is to be strictly avoided, ''lean'' mixtures are entirely necessary.

After the clays which enter the composition have been carefully sieved and prepared, they are measured into a lead or zinc-lined trough and are thoroughly mixed (dry), after which they are wetted with just sufficient pure, clean, lukewarm water to permit the thorough kneading of the mass, avoiding any excess of water, as an excess causes cracks and increases the shrinkage of the pots. This mass is called the ''batch,'' and after being wetted it is allowed to stand a couple of days before kneading. The kneading may be accomplished by the artificial masticating of the mass in a ''pug-mill,'' but the primitive method of ''treading'' constitutes the general process. This consists in tramping the mass little by little with the bare feet, as it was commonly supposed that the warmth, elasticity and sensibility of the naked feet, develop the plasticity of the clay in a manner not equalled by mechanical means. This operation is repeated several times at intervals of about thirty-six hours, by which means the materials of the batch are effectively bonded together, and all air bubbles, which would cause cracks in the drying process, are worked out. As another precaution, the material is formed into cakes which are thoroughly beaten, and a perfectly dense material is the result.

The pot is modeled upon a board or stone, covered with granulated pot shell or burnt clay, and after being finished, it must stand quietly in the place where it was made to avoid shaking until such time as it can be moved with safety. Care must be taken to continue the drying in such a uniform manner as will insure that the walls, top and bottom, dry in unison. This can be accomplished by covering the pot with linen, and maintaining a uniform temperature not exceeding 65°, during the first stages of the drying process. In the pot room all draught must be excluded, as the slightest draught causes fire cracks; even the direct rays of the sun should be excluded.

After the pot is sufficiently dry so that it can be moved with safety, it is advisable to place it upon a drying frame, and in a room where a temperature of about 90° can be maintained. The period of drying depends chiefly upon the size of the pot, and the time varies from four to twelve months. Too much cannot be said regarding the exercise of care and prudence in tempering the pots in the pot-arch, and their transfer to the furnace. The time occupied in tempering varies from four to seven days, and the result of this process adds or detracts much to or from the average life of a pot. Equal care must be exercised when the pots are tempered direct in the furnace, as is the custom with many manufacturers, especially at the beginning of a season.

Pots are exposed to three dangers: Actual weight of melted glass; intense and prolonged heat; and the corrosion of raw materials within the pot. As the strength and resistance of the pot depends upon the materials from which it is made, their manipulation, and the care with which it has been tempered and "placed," the first two dangers are proportionate thereto. The internal corrosion is also augmented or resisted by like conditions, but can be at least retarded by "glazing," which consists in partially filling the pot with clean glass cullet, free from any flux, which, after it melts, is spread over the interior surface of the pot; this imparts to such surface a thin so-called "glaze," which prevents the deposit of clay from the sides of the pot by retarding corrosion. In "glazing" pots intended for the production of "colors," it is always advisable to use a more refractory glass than that which is to be melted in them—a glass highly silicious, and melted at a high temperature. Pot-makers also avoid all sharp corners, which would facilitate corrosion. Those common faults in most glass, "cords," and "stones," are frequently nothing more or less than an infusible aluminate formed by the combination of the alkaline or metallic ingredients of the glass, with the alumina of the pot, torn down by corrosion. Some materials, as lead, cryolite, etc., are much more severe in attacking the pots than others.

The life of the pot cannot be predicted, and the breaking of a single pot often disturbs the furnace to such an extent, and others follow so frequently, that weeks will sometimes elapse before a complete reorganization can be effected. The very "wear and tear" and exposure of the others while setting one pot, is often sufficient to cause excessive breakage among the balance in the furnace. There are so many things seemingly unimportant which affect the average life of a pot, that it is difficult to define any real cause for breakage without involving other causes. Defective composition, injudicious handling, improper annealing, "starvation" by exposure to cold air while in the furnace, variation in furnace temperature, disintegrating action of corrosive materials, and many other causes can be ascribed. One especial precaution is to be recommended, that of reheating a pot after being "worked out," and before filling it with cold batch. In window glass furnaces the pots as a rule, are all reheated, but in flint furnaces they are not. If the pots are closed up for an hour prior to the introduction of the filling, they become able to resist the chilling influences of the cold batch; besides, the melt begins almost immediately, whereas, if the pot is chilled, the melt is retarded until the pot does become properly heated.

In connection with fire clays we quote the following regarding some interesting experiments made by Mr. J. D. Pennock, to determine the heat, conductivity, expansion and fusibility of refractory clays in the form of fire brick; in which he used those made from Grecian Magnesite, American Magnesite, Silica Brick and Belgium coke oven tiling. The following table shows their conductivity of heat respectively: Grecian, American, Silica Brick, and coke oven tiling; also their respective analyses, specific gravity, etc. As silica brick are now so extensively used in furnace construction, the following table gives interesting data:

Brick	Expansion of Core.	Per 12// Brick	Aanlysis SiO_2	Fe_2O_3+ Al_2O_3	CaO	MgO	Specific Gravity	W'g't Per Cu ft.
Grecian magnesite	07	.11	2.16	.72	4.20	93.03	3.54	170.2
" "	.07	.11						
American magnesite	.067	.10	3.10	6.64	3.76	86.50	3.44	160.9
" "	.057	.088						
Coke Oven Tiling	.05	.076	69.89	27.75	.27	.17	2.56	109.9
" " "	.05	.076						
Silica Brick			94.07	3.66	1.39	.19	2.54	111.4

THE PRINCIPLES OF ANNEALING AS APPLIED TO GLASS.

When we say that reliable strength and durability can, at present, only be imparted to glass by annealing, we have the entire context of the subject before us.

The process of annealing is a distinct feature of the glass industry, yet notwithstanding its importance, there is possibly no other feature so little understood. Manufacturers seem generally content with the primitive methods that have been handed down from generation to generation, without making much perceptible effort towards definite improvement of the process, except perhaps in fuel. In this direction some advance has been made, as well as some improvements in general construction and appliances, although these improvements have been brought about with a view to facilitate the handling of the generally increased factory production, and not, we regret to say, with much regard to improvement in the application of the true hypothesis of annealing and its principles. The opportunities presented by the general improvement in fuel, and appliances for generating and manipulating heat; the advance in structural material; and the economy of modern methods of manufacture, as illustrated by other lines of industry, should surely be an incentive to the glass manufacturer to leave the foot-worn paths of imitation and endeavor to improve his own methods to meet the demand of modern trade.

Annealing means to heat a substance, like glass, and then allow it to cool gradually. There are at present but two successful methods of doing this: One by gradually withdrawing the glass—after being heated—from the heat; the other by allowing the source of the heat to gradually become extinct. The first is applicable generally to "lehrs," and the latter to "ovens."

From a scientific point of view, the hypothesis of the repulsive force between the molecules of a substance when excited by heat, is possibly the best explanation of the various phenomena connected with the cooling of heated glass. The force excited by heat has a tendency to cause all bodies to expand, and eventually change their condition of aggregation; the body passing by gradual change from a solid to a liquid, and from a liquid to a gaseous condition—if continued far enough as the physical pores, the existence of which this hypothesis assumes, increase in size by expansion. Therefore if the increase in size of its intermolecular pores causes the liquidity of glass, it is not too much to assume that the gradual diminution or decrease in size of these same pores will result in the various stages of viscosity, ductility and solidity of the same substance. But if the glass is cooled rapidly, the outside walls become intensely solidified, while the molecules of the interior are withheld from uniting and reducing the internal porosity by adhesion to the solidified exterior. This difference in condition is aggravated by the poor conductivity of heat by glass. While in this condition, the glass is withheld from collapse by the intense solidity of its exterior walls. As soon as the solidity of these is weakened, disintegration naturally ensues. This is generally true of all glass cooled rapidly. On the other hand, if the glass is allowed to cool gradually there is a gradual coalition of its molecules; its pores become regularly and uniformly closed and dinminished in size throughout the entire substance, and it acquires regular and reliable strength.

Practically speaking, during the process of making and finishing articles of glass, there is always an unequal chilling and contraction of parts, the thinnest parts cooling quickest, and the outside walls, on account of exposure to air, and contact with "block," "marver," molds or tools, chill and contract more than the interior. This creates layers, strata, and general lamination of the structure. This structural defectiveness is caused by the irregular rushing of the molecules to adjust themselves during the process of cooling, being governed in their movements by the rapidity of the decrease in temperature and exposure to chilling influences. The now apparent object in annealing is to obviate this irregular molecular adjustment and its effects, by reheating the manufactured articles to such a point, where, by expansion the molecules are enabled to coalesce and then cool gradually, and in so doing allow the "metal" to contract in a manner to avoil molecular strain, by allowing the molecules to re-set themselves in unison from the center outward, thus reversing the original cooling process.

While annealing is of paramount importance, it is a distinct process of itself, and is inadequate to correct all the various imperfections contingent to the manufacture of glass. If the glass is allowed to chill too much prior to its introduction to the influences of the annealing process, its structure becomes so seriously laminated, that its faults are beyond correction by annealing; from which it is readily assumed, that the quicker it is exposed to the influences of the annealing process, and the more heat retained by it when introduced to such process, the more beneficial the effects of annealing become. While the different methods of annealing are coducive to the same general lines, yet their various results are not strictly parallel, some being naturally better than others.

The vital point in all annealing is uniformity and regularity, and is the keystone of the whole process. Heat, its source, generation, uniform distribution and maintenance, constitutes the cardinal feature of the process irrespective of method, and uniformity of result is commensurate with its consideration. So far as appliances for annealing are concerned, it would require an article of much length to define the various constructions—primitive and modern, and inasmuch as they are all constructed along a common line, so to speak, parallel in method, we will forego any attempt at description.

Of fuels for annealing purposes there are a variety, producing various results, which require more than passing mention, inasmuch as they are conducive to the general result, be it good or bad. Wood, coke, gases (natural and artificial), and sundry oils, constitute the principal fuels. The latter mentioned—gases and oils—are productive of better results than coke or other fuel burnt by direct process of combustion over a grate. Oils on account of their cost and danger, until recently were not much used, although the results of their use have been efficient and satisfactory. However, recent appliances and methods have been devised that enhance the value of oil as a fuel, and insure its use with comparative safety, and it is steadily gaining favor as an economical, effective fuel. Coke and gas are at present possibly the most extensively used fuels for annealing, but of these gas produces the best results, both from a point of efficiency and economy. Coke or wood fired appliances, as ovens and lehrs, are generally built in the old primitive way, with the fire-box or furnace on one side, separated from the oven or lehr proper by a bridge or fire-wall over which the flame and heat pass. In this method of construction there is a deficiency. This deficiency in a coke or wood fired appliance is that the bottles—by way of illustration—piled next to this fire-wall receive obviously more heat than those along the opposite wall. Besides with a coke fire the temperature is greatest when the entire bed of coke is ignited and aglow; eventually this temperature decreases until it becomes necessary to replenish the bed of fire with fresh coke, which further reduces the temperature. As the freshly added coke becomes ignited the temperature is again increased in proportion to a point of thorough ignition, until it again becomes necessary to replenish the supply. This fluctuation of temperature creates a corresponding irregularity in the annealing process. Again, coke absorbs moisture from the atmosphere and this moisture is expelled from the freshly added coke and becomes mingled with the heat. Variableness of draught through the grate; variation of heat producing qualities of the different cokes; excess of carbon; irregularities in firing, etc., all produce irregularities in temperature and hence irregular results. Some of these deficiencies have been eliminated by a modern improvement in lehr construction, by placing the fire box beneath, and leading a series of flues up, and opening into each side, which facilitates a better distribution of the heat, and combustion.

With the use of oil or gas a majority of these discrepancies are entirely eliminated. Gas or oil jets and burners can be placed where they will be most efficient, and the article or articles undergoing the process, can be virtually surrounded with a flame line, and a simple turn of a valve insures a regular supply of fuel, which properly placed effects a regular heat supply —the required essential. We say ''properly placed.'' The meaning of this is, that some manufacturers in making the change to oil or gas as fuel, simply pull out the grate bars and introduce the oil or gas pipes into the openings left, and continue to fire from one side of the appliance. This is not proper placing for reasons above mentioned. The theory is void without practical execution, and without a regular, uniform heat supply and distribution, the essential features of the process are void. There is also an absolute necessity for uniform, constant and regular ''heating up'' and ''cooling down'' during the process, by permitting the product undergoing the process to approach the point of temperature necessary, regularly, and recede therefrom in like manner, not abruptly, as it is not the simple act of re-heating and then allowing to cool without regard to system and concordant principles, that effects the purposes of annealing. The process involves systematic lines of procedure by allowing the articles in question to approach the proper temperature, with due method, consistent with regard to conditions of introduction, and after absorption of sufficient heat, methodical withdrawal therefrom. Nor is this all. Too much heat is possible, and the product may be spoiled in part or wholly. As to the actual temperature, circumstances govern this point, yet the temperature should be maintained at the highest possible point consistent with the safety of the product in process. Usually the temperature ranges from 600° to 1,000° F, averaging about 800° F. There is no excuse for lack of determination and maintenance of a fair average temperature. The day of measuring the heat ''by the eye'' is past and gone; pyrometric instruments designed for accurate heat measurement can be obtained at a very nominal figure, consistent with their commensurate value.

Aside from the usual annealing process, various experiments have been conducted with a purpose to devise means to harden, temper or toughen glass, with a view to supercede the regular process of annealing. In 1875 M. Alfred de la Bastie announced that he had discovered a method of tempering glass in such a manner that its strength would be greatly increased. He assumed that the cohesive weakness of its molecules caused the fragility of glass, and that if the molecules could be forced closer together the strength of the material would be increased. Failing to accomplish this result by mechanical compression of the glass while hot and viscid, he endeavored to bring about the same result, after numerous experiments, by immersion of the heated article in a bath of melted tallow or mutton fat at a temperature 68-75° C, (154-167° F,); in this he was successful in certain lines.

Mr. F. Siemens was another inventor who experimented in this direction with some success. He conceived the idea of tempering the articles by placing them in molds between cooled surfaces, thus maintaining their shapes intact, and applying force if necessary, so as to press the molecules of the glass firmly together.

Piper's process consists of heating the glass almost to the point of plasticity, and then subjecting it to the action of injected superheated steam, which produces a result about similar to De la Bastie's.

These processes are attended with such difficulties as to modify to a certain extent their success. Besides they do not furnish as supposed, a substitute for annealing. They produce hardened glass, not annealed glass; and while hardened glass will undoubtedly stand rough usage better than ordinary glass, yet it is not unbreakable, and upon the slightest fracture it will become utterly disintegrated. The glass is hard, not tough, and it is the very opposite of annealed glass. Hardened glass is that in which the molecules have been tortured into their position; while in annealed glass the molecules have been allowed to settle themselves. Glass hardened by thess processes is impaired for practical utility by its inability to be cut and fashioned, and its utter destruction by the slightest fractures. These are difficulties which have baffled the ingenuity of all producers of toughened glass.

In conclusion we say that reliable strength and durability can only be imparted to glass by uniform annealing. But in this the various fields presented by the factors, heat, and its uniform maintenance and distribution; appliances for utility and economy of process; mechanism for successful manipulations, etc., present excellent and unlimited opportunities for progressive manufacturers to develop more modern and successful methods of annealing.

The following tabular statement will illustrate the resistance and nature of fracture of glass under different methods of annealing:

Method of Annealing	No. of Tests.	Resistance of kilogram per sq. m. m.	Nature of Fracture.
Cooled in annealing oven	1 2 3	5.87 5.68 4.69	Clear surface breakage.
Cooled in open air	1 2 3 4	12.66 9.52 9.90 7.22	A piece of upper surface thrown off 80 m m 150 m m 80 m m 20 m m in length.
Rapidly chilled to 100 deg. from			
(*a*) Low red heat	1 2	36.81 32.47	Numerous surface cracks.
(*b*) Medium red heat	1 2	17.98 20.51	Numerous splinters flew off during cooling process.
(*c*) Bright red heat	1	54.22	Audible detonation at splintering.
Rapidly cooled to 120 deg. from			
(*a*) Low red heat	1 2 8 4	21.58 96.24 23.65 12.03	Exceptional strong splintering.
(*b*) Medium red heat	1 2	31.97 32.83	
[*c*] Bright red heat	1 3 3	32.49 29.68 36.03	Faultless tubes.
Rapidly chilled to 140 deg. from			
[*a*] Low red heat	1 2	3 10.13 1.82	Splintering during process; faulty tubes,
[*b*] Medium red heat	1	41.60	
[*c*] Bright red heat	1	36.33	
Rapidly chilled to 180 deg. from			
[*a*] Low red heat	1	23.86	
[*b*] Medium red heat	1	16.65	
[*c*] Bright red heat	1	38.72	

WINDOW GLASS.

Analyses of Window Glass.

	French. (Dumas.)	English. (Dumas.)	Chance's. (Cooper.)	Russian. (Benrath.)
Silica	68.00	69.00	71.40	71.27
Soda	10.10	11.10	15.00	20.10
Lime	14.30	12.50	12.40	8.40
Alumina	7.60	7.40	0.60	

It is well to bear in mind that window glass is subjected to indefinite exposure to the weather, the action of which, under continued exposure generates chemical influences deleterious to the glass; hence the glass should be so constituted as to afford the greatest resistance. In its constitution the silica should always be as high as possible. Manganese and oxide of nickel may be used as decolorizers, but are not recommended; especially manganese, as under the continued action of sunlight the color in glass containing manganese is not constant, and sometimes assumes an undesirable violet tint. With the use of oxide of nickel the color is more consistent, but arsenic is used as the principal decolorizer in most window glass.

WINDOW GLASS RECIPES.

English Window Glass.

—1—

Sand	60	Saltpetre	15
Pearl-ash	30	Borax	1
Arsenic	½		

—2—

Sand	60	Arsenic	2
Pearl-ash	25	Salt	10
Saltpetre	5	Magnesia	1½

—3—

Sand	60	Arsenic	2
Pearl-ash	30	Salt	10
Magnesia	2		

—4—

Sand	560	Cabonate of sodium	119
Sulphate of sodium	63	Chalk	154
Arsenic	2		

—5—

Sand	448	Carbonate of sodium	168
Sulphate of sodium	17	Chalk	146
Aresnic	2		

French Window Glass.

—6—

Sand	100	Chalk	35 to 40
Soda ash	28 to 35	Arsenic	0.20
Manganese	0.25		

—7—

Sand	100	Lime	6
Sulphate of sodium	44	Powdered coal	4

—8—

Sand	100	Lime	13 to 15
Sulphate of sodium	58 to 75	Powdered coal	4.5 to 5.5

—9—

Sand	100	Charcoal	1½
Salt cake	35	Manganese	⅜
Lime	25	Arsenic	1
Cullet	100		

—10—

Sand	100	Charcoal	4
Salt cake	42	Arsenic	1½
Lime	34	Cullet	100

Belgian Window Glass.

—11—

Sand	100	Carbonate of calcium (chalk)	40
Salt cake	36	Charcoal	2
Cullet	100		

—12—

Sand	100	Carbonate of calcium	38
Salt cake	42	Charcoal	4
Cullet	100		

Bohemian Window Glass.

—13—

Sand	100	Slacked lime	12
Potash	40	Arsenic	¼
Saltpetre	2	Cullet	100

—14—

Sand	100	Slacked lime	14
Potash	40	Arsenic	½
Salt	5	Cullet	100

German Window Glass.

—15—

Sand	100	Nitrate of sodium	2
Soda	40	Charcoal	3
Slacked lime	35	Arsenic	1

—16—

Sand	100	Nitrate of sodium	6
Soda	40	Charcoal	6
Slacked lime	35	Arsenic	2

American Window Glass. (Salt Cake.)

—17—

Sand	8000	Lime	2500
Sulphate of sodium	2200	Powdered coal	40
Arsenic	50		

—18—

Sand	100	Lime	24
Salt cake	42	Charcoal	3½
Arsenic	1½		

—19—

Sand	100	Lime	31
Salt cake	35	Charcoal	7
Arsenic	1		

—20—

Sand	100	Lime	34
Salt cake	38	Charcoal	5
Arsenic	½		

American Window Glass. (With Soda.)

—21—

Sand	100	Soda ash	7
Salt cake	36	Arsenic	2
Lime	34	Charcoal	6

—22—

Sand	100	Soda ash	6
Salt cake	32	Arsenic	2
Lime	32	Charcoal	6

—23—

Sand	100	Soda ash	8
Salt cake	40	Arsenic	2
Lime	40	Charcoal	6

Crown Glass. Bohemian.

—24—

Sand	300	Lime	30 to 35
Soda ash	200	Cullet	200 to 300

—25—

Sand	100	Dry quicklime	17 to 20
Sulphate of sodium	50	Charcoal	4

—26—

Sand	400	Sulphate of sodium	560
Quicklime	486	Charcoal	25

—27—

Sand	650	Cullet	250
Quicklime	225	Pipe-clay	7
Soda	200	Nitre	7

—28—

Sand	300	Arsenic	4
Sulphate of sodium	100	Charcoal	1
Nitre	10	Manganese	3-16

—29—

Sand	400	Quicklime	64
Salt cake	200	Charcoal	16

—30—

Sand	600	Cullet	600
Ground limestone	66	Manganese	1
Soda ash	300	Cobalt	1-16

PLATE GLASS.

Analyses of Plate Glass.

	French		English						
	St. Gobian Peligot	French Dumas	Chances Benrath	British Plate Glasa Co Mayer	London and Thames Brazier	Betgian Charleroi Benrath	German Jaeckel	Hanoverian Emmerling.	Venetian Berthier
Silica	73.00	75.90	70.71	77.36	78.68	73.31	72.31	73.79	68.60
Soda	11.50	17.50	13.25	13.06	11.36	13.00	11.42	13.94	8.10
Potash	.....	.....	.....	3.01	1.34	.....	.....	0.60	6.90
Lime	15.50	3.80	13.38	5.31	6.09	13.34	14.96	8.61	11.00
Magnesia	.....	.....	.....	.....	.....	.....	.....	0.12	2.10
Manganese	.....	.....	.....	.....	.....	.....	.....	0.32	0.10
Sesqui-oxide of iron	.....	.....	1.92	0.91	trace	.83	.....	0.68	0.20
Alumina	.....	.....	.....	trace	2.68	.....	0.81	0.58	1.20

In view of the fact that plate glass requires a certain degree of perfection, as great brilliance, clearness and purity; a total absence of striae, cords, blisters, seeds and stones; permanence of color and durability, it can be readily seen that the purest materials only should be used, and these manipulated with great care. Color is a very important consideration, and for reasons already mentioned manganese should never be used. De Fontenay introduced the use of oxide of nickel, which imparts a bluish tint to glass and is constant in color. Oxide of zinc has been used in plate glass to replace manganese, but results have not been entirely satisfactory, as Gerner claimed that oxide of zinc was liable to impart a yellowish tinge, which experience confirms, particularly if the glass is not rapidly worked out after firing.

The older formulas encouraged the use of soda and potash, as in the earlier days of the industry a glass fluid and highly alkaline was required on account of the impurity of materials. But progressive economy, improved furnaces, etc., have gradually brought salt cake into very general use.

PLATE GLASS RECIPES.

Old English.

—1—

Sand	100	Lime (hydrate)	12
Soda	33	Manganese	0.5
Potash (refined)	6	Saltpetre	2
Cullet	100		

—2—

Sand	100	Lime (hydrate)	20
Soda (pure)	35	Saltpetre	2
Manganese	¼		

Ure.

—3—

Quartz sand	100	Lime	20
Sulphate of sodium	24	Cullet of soda glass	12

Vienna.

—4—

Quartz sand	100	Lime	20
Sulphate of sodium	50	Charcoal	2¾

French.

—5—

Sand	300	Carbonate of sodium	100
Cullet	50	Slacked lime	43

Bohemian.

Sand	100	Arsenic	0.5
Soda	33.33	Borax	0.5
Lime	30	Carbonate of nickel	.009
Nitre	2	Red oxide of cobalt	.0006
Plate glass cullet	100		

American Practice With Salt Cake.

—7—

Sand	720	Nitre	25
Sulphate of sodium	450	Charcoal	5
Quicklime	100	Plate glass cullet	425

—8—

Sand	100	Charcoal	2.5
Lime	35	Salt cake	38
Arsenic	2		

—9—

Sand	100	Lime	37
Salt cake	37	Charcoal	2.5
Arsenic	1.5		

—10—

Sand	100	Lime	38
Salt cake	40	Charcoal	4
Arsenic	2		

Graeger.

—11—

Sand	100	Salt cake	35
Carbonate of calcium	26	Charcoal	2.5
Saltpetre	2	Manganese	0.25

Knapp's Technology.

—12—

Sand	100	Soda	35
Lime	5	Cullet	100
Decolorizer			

St. Gobain; Old. (Analysis.)

—13—

Silica	72.1	Alumina and oxide of iron	1.6
Soda	16.0		

St. Gobain; Later. (Analysis.)

—14—

Silica	77.1	Lime	15.7
Soda	22.2	Alumina and iron	trace

Bastenaire.

—15—

Sand	100	Cullet	100
Soda	60	Peroxide of manganese	1
Carbonate of calcium	13	Smalt	.05

English Soda.

—16—

Sand	400	Carbonate of sodium	250
Chalk	30		

—17—

Sand	720	Carbonate of sodium	450
Nitre	25	Lime	80

Semi-White Sheet Glass Recipes.

—1—

Sand	500	Ground limestone	160
Baryta	140	Charcoal	10
Salt cake	70	Cullet	500

—2—

Sand	150	Carbonate of calcium	48
Salt cake	52	Charcoal	4.5
Cullet	125		

—3—

Sand	100	Slacked lime	12 to 14
Potash	45 to 50	Cullet	100
Salt cake	10 to 12	Charcoal	1

—4—

Sand	150	Cullet	100
Salt cake	45	Common salt	18
Charcoal	4	Ground limestone	45

—5—

Sand	100	Charcoal	3
Salt cake	45	Ground limestone	18

—6—

Sand	100	Charcoal	4
Salt cake	38	Ground limestone	26

White Sheet Glass Recipes.

—1—

Sand	100	Carbonate of calcium	26
Potash	60	Cullet	100

—2—

Sand	100	Cullet	100
Salt cake	38	Charcoal	3
Carbonate of calcium	33	Arsenic	2

—3—

Sand	100	Carbonate of calcium	38
Potash	8	Cullet	100
Salt cake	32	Charcoal	4

BOTTLE GLASS.

Bottle Glass Analyses.

Kinds of Glass.	Analysts.	Silica.	Soda.	Potash.	Lime.	Manga-nese.	Sesqui oxide of iron.	Alumina	Mag-nesia.
French....	Berthier....	60.00	3.10	3.10	22.30	1.20	4.00	8.00	.....
Sauvigny	"								
St. Etienne	"	60.40	3.20	3.20	20.70	.....	3.80	10.40	.....
Epinac....	"	59.60	.....	3.20	18.00	0.40	4.40	6.80	7.00
Sevres.....	Dumas.....	53.55	.....	5.48	29.22	.....	5.74	6.01	.....
Clichy......	"	45.60	.....	6.10	28.10	.....	6.20	14.00	.....
Bohemian.									
Champagne	Maumeno..	58.40	9.90	1.80	18.60	.....	8.90	2.10	.....
Champagne	"	62.21	5.69	1.91	22.93	.....	6.10	1.16	.....
German....	Benrath....	69.82	18.28	1.50	7.82	.....	2.58	2.58	.....
German...	Benrath....	62.78	19.14	11.24	6.11	.....	0.73	0.73	.....
Russian...	Benrath....	65.77	11.75	11.75	16.58	.....	5.90	5.90	.....
Russian...	Benrath....	68.38	19.03	19.03	10.19	.....	2.40	2.40	.....

By bottle glass is generally meant the common grades of glass used principally in the manufacture of bottles; as green, or amber colored varieties.

The so-called "lime flint" bottle glass figures largely at the present day in the bottle industry; in fact the past decade has wrought a revolution in so far as to give flint glass bottles much prestige. For a long time flint glass bottles were regarded with disfavor, inasmuch as their cost alone excluded them from the beer and soda water trade, to say nothing of the current belief rife among the bottling fraternity that flint glass lacked the strength and resistance of green glass; and that the liquid contents of a flint glass bottle were seriously impaired in strength and in color by the action of light, which a green or amber bottle excluded, and thus protected its contents. But these objections have been nominally overcome, especially the first, as the price of raw materials necessary for flint bottle glass is such that there is but little difference in the first cost, considering quality. Strength and resistance are acquired in glass by proportionate quantities of raw materials, proper melting and careful annealing, and the deteriorating effects of light are not considered serious. Without doubt flint glass bottles command favor; and even much of the green bottle glass of the present day assumes a similarity to flint which in many cases leaves a difference in color difficult to determine. Improved furnaces, decolorizers, purity of materials, etc., make such possible, and competition demands it.

Regarding any glass intended for bottles, it is well to remember that competition augments economy, and much discretion must be exercised to combine economy and stability. Regarding stability, it is well to keep in mind that resistance to corrosion and strength increases in proportion with the amount of sand melted—the product also cheapens accordingly—but difficulty of fusion is increased in proportion; and what is true in regard to sand is just the reverse with regard to the alkaline bases as in proportion with increase in alkali, is resistance decreased, fusion facilitated, and cost increased. Alumina increases resistance, but in excess renders glass liable to devitrification. Lime improves polish and brilliance, hardens the product, and aids resistance, but retards fusion when used in excess. Difficulty of fusion increases generally with decrease of solvents. Resistance also decreases with increase of cullet.

Regarding economy, cheap grades of sand can be used in the ordinary green and amber glasses; the iron and alumina always present in impure sand are not objectionable, as both are frequently added purposely. Salt cake furnishes a cheap solvent, but for reasons stated elsewhere, all traces of salt water must be removed before coloring oxides are added. Zaffre for blue, manganese for violet or black, and pulverized charcoal, cannel or anthracite coal for amber, furnish possibly the cheapest coloring agents.

Slag Glass.

The idea of manufacturing glass from the waste cinder, or slag, of iron blast furnaces is by no means a new one. Iron slag contains many of the ingredients of common glass, and it is possible that much of the early glass was metallurigical slag remelted. The sands prepared by pulverizing slag have been used in England, and on the continent of Europe for a long time as a constituent of glass.

An analysis of Welsh iron slag shows:

Silica	40
Lime	35
Alumina	16
Magnesia	6
Alkali	1
Oxide of iron	2
	100

A trace of sulphur is found associated with the lime in slag, but this readily passes away with heat. When the consistency of slag is once determined by analysis, and the proper proportion of additonal materials has been determined, a very regular and uniform workable glass can be made, as actual experience has shown conclusively that the composition of slag is regular enough to warrant results sufficiently uniform for all practical purposes. Taking the above analysis as an example, it will be seen that the principal differences are in the silica, alkali and iron; but by combining 100 parts of slag, 10 parts of soda and 60 parts of sand, the constituents are altered to a compound of the precise nature required, thus:

Slag.		Additions.		Glass.	
Silica	40	Ferruginous sand	60	=100	or 57.14%
Lime	35	....		= 35	or 20.00%
Alumina	16	....		=16	or 9.14%
Magnesia	6	....		= 6	or 3.43%
Alkali	1	Soda	10	=11	or 6.29%
Oxide of iron	2	From the sand	5	= 7	or 4.00%
	100			175	100

The natural tint of the glass thus produced is greenish in color, but by "fining" and bleaching it can be made almost colorless. With some ores the slag contains silica enough, and with the addition of soda and arsenic becomes perfectly transparent. The constituents of slag are common to all green glass, and by dilution with purer materials, decolorizers, etc., slag glass can be brought up to almost any desired standard, consistent with the iron and other impurities in its constituency. However, without attempting to predict the possibilities of its manufacture in the future, so far its use has been confined to the ordinary black, dark green and amber colored bottle glass.

FLINT GLASS—(CRYSTAL.)

Analysis of Lead Glass.

Glass.	Anaylst.	Silica	Soda	Potash	Lime.	Lead.	Iron	Alumina.
English crystal	Faraday	51.93	.....	13.67	.....	33.28	.....	.....
English crystal	Berthier	59.20	.....	9.00	.....	28.20	0.40	.....
French crystal	Sauerwein	48.10	.....	12.50	0.60	38.00	0.50	.....
French crystal	Benrath	50.18	.....	11.62	.....	38.11	1.30	1.30
American crystal	Fletcher	53.98	6.71	7.60	.....	29.78	1.93	1.93
American crystal	Fletcher	54.12	5.58	7.98	.....	31.27	1.05	1.05

Analysis of Lime Glass.

Glass.	Analyst.	Silica.	Soda.	Potash.	Lime	Magnesia.	Manganese.	Iron.	Alumina.	Baryta.
French	Pelouze	72.10	12.40	.....	15.50	.....	.....	.....	.....	.....
" tubes	Berthier	69.20	3.00	15.80	7.60	2.00	.....	9.50	1.20	.....
Bohemian	Rowney	73.13	3.07	11.49	10.43	0.26	0.46	0.13	0.30	.....
American	DeBrunner	71.92	14.55	.....	5.14	2.04	.....	.....	6.22	.....
American	Henrivaux	70.40	9.13	8.66	10.00	.....	0.50	0.02	0.99	.....
American	Benrath	67.10	10.30	4.20	5.10	.....	.....	0.10	0.30	11.90

Under the caption of flint, or crystal glass, many varieties of glass may be properly classed; and while there are different grades of flint glass, yet it is important to recommend the use of the best materials for the finer grades. Of course for the manufacture of ordinary hollow ware, a glass made from cheaper materials may be entirely satisfactory. Such titles as "lead flint," "lime flint," tank flint," "German flint," etc., are applied to glasses graded according to materials used and circumstances contingent to their manufacture. It hardly seems necessary to specially define any of them, but rather remark a few especial features in their manufacture, and refer the reader to a list of well selected recipes. Old recipes for crystal glass called for less lime than is in use in present day practice; as a result the glass now has a higher polish and more resistance; but it must be remembered that an excess of lime retards fusion, and renders glass refractory and liable to devitrification. To avoid repetition we refer the reader to the data given in preceding pages regarding the materials in use and their respective actions and effects in glass.

As a basis for a good soda-lime glass, it is said that the composition must approach: Lime, 1, soda 1, sand 6. Benrath recommends the following: Sand 77, soda 14, lime 9, but circumstances modify conditions and must govern the proportion of all materials. In lead glass the yellowish tint imparted by the lead must be neutralized with decolorizers, as manganese, oxide of nickel, cobalt, etc. The same applies to the bluish green tint imparted by soda.

BOTTLE GLASS RECIPES.

Belgian (Colne.)

—1—

Sand	100	Pearl ash	20
Sulphate of sodium	15	Limestone	5

Green Bottle Glass With Salt Cake.

—2—

Sand	100	Ground lime	34
Salt cake	38	Charcoal	5

—3—

Sand	100	Ground lime	38
Salt cake	40	Charcoal	6

Green Bottle Glass With Soda.

—4—

Sand	100	Lime	32
Soda	35	Cullet	100

——5——

Sand	100	Lime	38
Soda	40	Cullet	100

Amber Glass Recipes. (For Bottles.)

——1——

Sand	100	Salt cake	40
Lime	38	Charcoal	8
Cannel coal	14		

——2——

Sand	100	Lime	35
Soda	33	Cannel coal	11

——3——

Sand	100	Salt cake	34
Lime	32	Charcoal	4
Cannel coal	8		

——4——

Sand	100	Lime	30
Soda	35	Charcoal	9

LEAD (CRYSTAL) GLASS RECIPES.

English. (Pellat.)

——1——

Sand	336	Potash	112
Lead	224	Saltpetre	14 to 28
Manganese	¼ to ¾		

English.

——2——

Sand	100	Borax	0.1
Soda (90%)	39	Nickelous carbonate	.0008 to .01
Minium (red lead)	51	Red cobaltous oxide	.0005
Nitre	3	Cullet	100

English Crystal.

——3——

Sand	300	Cullet	300
Lead	200	Saltpetre	48
Potash	80	Manganese	¾
Arsenic	1		

English Crystal.

——4——

Sand	100	Cullet	100
Lead	80	Saltpetre	0.5
Potash	40	Manganese	0.4

French Crystal.

——5——

Sand	150	Cullet	100
Lead	90	Borax	6
Potash	40	Manganese	1-10
Arsenic	1-10		

Loysel.

——6——

Sand	100	Potash	35 to 40
Lead	80 to 85	Nitre	2 to 3
Manganese	0.5		

Dumas.

——7——

Sand	300	Potash	110
Lead	215	Saltpetre	10
Borax	12		

——8——

German Crystal.

Sand	300	Cullet	100
Lead	160	Manganese	1¾
Potash	105	Lime	60

American Crystal.

——9——

Sand	1500	Saltpetre	150
Lead	600	Manganese	1½
Potash	500	Arsenic	1½

Soft With Cullet.

——10——

Cullet	400	Lead	10
Sand	10	Pearl ash	10

——11——

Sand	336	Nitre	28
Lead	224	Manganese	5-32
Pearl ash	112	Arsenic	1-16

Best Flint.

——12——

Sand	450	Nitre	38
Lead	250	Manganese	⅛

Pearl ash	125	Arsenic	½
Borax	1½		

—13—

Sand	900	Nitre	100
Lead	600	Manganese	1-16

Pearl ash, 300 to every cwt. of batch

—14—

Sand	500	Nitre	75
Lead	160	Manganese	⅜
Pearl ash	150	Phosphate of calcium	½

—15—

Sand	600	Lead	400
Pearl ash	130	Nitre	75
Manganese	¾		

—16—

Sand	100	Pearl ash	18
Lead	48	Soda	16
Nitre	6	Arsenic	9-64
Manganese	1-16	Antimony	1-64

Good.

—17—

Sand	2100	Lead	750
Pearl ash	600	Manganese	2
Nitre	250	Arsenic	2

Cheap.

—18—

Sand	200	Nitre	10
Pearl ash	75	Borax	⅝
Lead	80	Arsenic	1
Manganese	½		

—19—

Sand	270	Nitre	10
Lead	200	Arsenic	⅛
Pearl ash	90	Antimony	⅛
Manganese	⅛		

—20—

Good sand	3000	Ground limestone	260
Potash (90%)	1000	Nitre	110
Minium (red lead)	1500	Manganese	3
Cullet	3000		

KILN METAL.

—21—

Sand	360	Nitre	30
Lead	150	Arsenic	1
Pearl ash	125	Manganese	¼

—22—

Sand	500	Pearl ash	150
Lead	350	Nitre	30
Manganese	7-16		

—23—

Sand	100	Nitre	20
Lead	100	Aresnic	½
Pearl ash	100	Manganese	½

—24—

Sand	650	Nitre	22
Lead	250	Phosphate of sodium	6
Pearl ash	300	Phosphate of calcium	1½
Manganese	½		

Three-fourths Kiln Metal.

—25—

Sand	720	Nitre	60
Lead	470	Borax	5
Pearl ash	240	Manganese	¾

Lead, Soda.

—26—

Sand	252	Nitrate of sodium	56
Litharge	140	Manganese	5-16
Soda	98	Arsenic	⅛

Baryta, Lead.

—27—

Sand	260	Carbonate of barium	400
Potash	160	Oxide of lead	200

Baryta, Soda, Lead.

—28—

Sand	350	Oxide of lead	230
Carbonate of barium	300	Soda	100

Baryta, Potash.

—29—

Sand	500	Potash	200
Carbonate of barium	300		

LEAD FLINT FOR OPEN POTS.

—30—

Sand	500	Cullet	450
Lead	200	Saltpetre	40
Potash	160	Manganese	1

—31—

Sand	200	Carbonate of calcium	30
Lead	25	Cullet	90
Manganese	1		

OPTICAL GLASS.

Optical glass is difficult to make and its processes are carefully guarded, so but little can be said regarding it except that the glass must be perfectly homogeneous and absolutely free from all stratification, as difference in density creates corresponding differences in the light refracting powers of the glass.

OPTICAL GLASS RECIPES.

Chances'.

	1	2	3		1	2	3
Sand	100	100	100	Potash	30	25	26.66
Lead	67	128	105	Saltpetre	3 1-3	2	4.8

Guinaud.

—2—

Sand	100	Borax	1.75
Lead	100	Manganese	0.45
Potash (pure)	23	Arsenic	0.45
Saltpetre	1.33	Cullet	22

Bontemps.

—2—

Sand	100	Cullet	30
Lead	100	Borax	
Potash			

Bontemps.

—4—

Sand	100	Potash	23
Lead	100	Borax	6.5

Bontemps.

—5—

Sand	100	Potash	26
Lead	100	Saltpetre	6.75
Borax			

LIME FLINT GLASS RECIPES.

Bohemian.

—1—

Sand	100	Nitre	1.25
Potash	35	Green nickel carbonate	0.007
Burned lime	19	Cullet	100

—2—

Sand	100	Cullet	100
Potash	25	Soda	5
Burned lime	20	Minium	32
Arsenic	0.75		

—3—

Sand	100	Cullet	100
Potash	25	Soda	10
Burned lime	17	Arsenic	1.5
Nitre	0.5	Manganese	0.05

—4—

Sand	100	Arsenic	0.5
Soda	42	Borax	0.5
Limestone	25	Carbonate of nickel	.010
Nitre	2	Red oxide of cobalt	.0006
Cullet	100		

Lippincott.

—5—

Quartz sand	100	Chalk	8
Carbonate of potassium	,60	Manganese	.75

French.

Colne.

—6—

Sand	300	Lime	75
Carbonate of sodium	170	Charcoal	10

Lippincott.

—7—

Sand	100	Lime	18
Carbonate of potassium	30	Manganese	0.5

Belgian.

—8—

Sand	100	Carbonate of calcium	24
Soda (95%)	32	Charcoal	2.5

—9—

Sand	100	Carbonate of calcium	24
Soda (95%)	46	Charcoal	2.5

American Practice.

——10——

Sand	400	Lime	35
Soda	155	Manganese	2
Saltpetre	20	Arsenic	2

——11——

Sand	550	Lime	35
Soda	170	Manganese	1
Saltpetre	35	Arsenic	¾

——12——

Sand	560	Lime	55
Soda	190	Manganese	½
Saltpetre	20	Arsenic	1

Henrivaux.

——13——

Sand	100	Lime	13
Soda	37	Arsenic	0.5
Nitrate of sodium	8	Manganese	0.15

Henrivaux.

——14——

Sand	100	Ground lime	25
Soda	25	Potash	8.5
Cullet	50		

Henrivaux.

——15——

Sand	100	Potash	33
Soda	33	Ground lime	25
Cullet	115		

Gas Belt.

——16——

Sand	1500	Arsenic	5
Soda	550	Manganese	2
Nitrate of sodium	80	Powdered blue	5-32
Bone ash	4		

Good.

——17——

Sand	1500	Nitrate of sodium	1
Soda	500	Arsenic	2
Ground lime	150	Manganese	2
Smalt	⅛		

——18——

Sand	1500	Antimony (needle)	1½
Soda	550	Manganese	2
Ground lime	150	Smalt	⅛
Nitrate of sodium	100	Borax	2

——19——

Sand	120	Cullet	50
Soda ash	60	Arsenic	⅛
Carbonate of calcium	30	Manganese	½

Cheap.

——20——

Sand	200	Arsenic	¼
Nitrate of sodium	2	Manganese	1
Cullet	60	Sulphate of sodium	120
Charcoal	2		

Cheap.

——21——

Sand	180	Manganese	½
Nitrate of sodium	10	Sulphate of sodium	75
Arsenic	¼	Charcoal	¼
Common salt	20		

Philadelphia.

——22——

Sand	1400	Nitre	100
Soda	530	Arsenic	¾
Lime	230	Manganese	¼
Gray zaffre	⅝		

With Potash.

——23——

Sand	300	Lime	50
Potash	90	Nitre	6
Manganese	1½		

With Potash.

——24——

Sand	500	Lime	60
Potash	165	Nitre	5
Manganese	1		

Baryta, Potash, Lime.

——25——

Sand	520	Lime	70

Potash	70	Oxide of lead	100
Carbonate of barium	100		

Baryta, Soda, Lime.

—26—

Sand	600	Carbonate of barium	210
Soda	110	Lime	80

CHEAP FLINT GLASS RECIPES FOR HOLLOW WARE.

—1—

Sand	300	Quicklime	75
Soda ash	150	Cullet	275
Arsenic	½		

—2—

Sand	240	Carbonate of calcium	50
Soda ash	120	Arsenic	½
Nitrate of sodium	2	Manganese	⅝

With Potash.

—3—

Sand	100	Saltpetre	2
Potash	50	Manganese	.02
Lime	20	Cullet	100

—4—

Sand	100	Manganese	½
Potash	40	Cullet	100
Slacked lime	40	Arsenic	2
Saltpetre	8	Salt	16

With Soda.

—5—

Sand	100	Saltpetre	1½
Ground lime	36	Manganese	½
Soda	30	Cullet	100

—6—

Sand	100	Arsenic	2
Ground lime	4	Manganese	1½
Soda	34	Cullet	100

With Salt Cake.

—7—

Sand	100	Charcoal	3
Salt cake	35	Arsenic	1
Ground lime	32	Manganese	½
Cullet	100		

—8—

Sand	100	Charcoal	6
Salt cake	40	Arsenic	2
Ground lime	38	Manganese	1½
Cullet	100		

COLORED GLASS.

Light and Color.

As light is the true source of color, it is necessary to examine its constitution to obtain an understanding of the fundaments of color. When a sunbeam shines through a prism the ray is not only bent from its course, but it is spread out fanlike into what is called the solar spectrum, showing six prominent colors, viz.: violet, blue, green, yellow, orange and red. If we pass the spectrum through a convex lens it will show a white spot; we therefore conclude that white light is composed of six colors. They are separated in the spectrum because the prism bends them unequally, violet being refracted most, red least. These colors are divided into three primary, or simple colors: red, blue and yellow; and three secondary or mixed colors: orange, green and violet. Orange is the result of a combination of red with yellow, green, of blue with yellow, and violet, of blue with red.

The primary colors are pure and cannot be produced by mixing other colors; their color may vary in intensity, but it cannot vary in hue; while the secondary colors may vary in hue indefinitely, according to the primary colors of which they are formed. The analysis goes further: Two colors, which by their mixture produce white light, are termed complementary to each other, and herein arise the complementary colors. Thus, if we sift the red out of a beam of light, and bring the remainder to a focus, a green image will be formed; hence red is termed the complementary of green. We assume that white light is composed of but three colors: Red, blue and yellow; the absent color from the compound is termed the complementary; and this complementary of any primary color is the secondary or mixed color composed of the two primary colors. Thus, the complementary of red is green, (blue and yellow); the complementary of blue is orange, (red and yellow); the complementary of yellow is violet, (red and blue). Any given color may be modified and appear very different, according to the circumstances under which it is seen; contrast of tone; the glazed surface of the colored substance; form of object containing the color; quality of the light by which it is illuminated, (if light be added to a color it is tinted; if taken from a color it is shaded; thus—yellow tinted, would be light yellow, while a yellow shade would be a dark yellow). As an illustration take red, and its tone and intensity may be modified by placing it in contact with other colors. Placed in contact with white it appears lighter; with grey it appears brighter; with black, duller; with blue, yellower; with yellow, bluer, and with green, purer and brighter, as a color is always heightened by being placed near to, or in contact with its complement.

When light passes through a transparent substance if all its vibrations are transmitted in the same proportion in which they exist in white light, the body appears colorless; but if some of the vibrations are absorbed or extinguished, the transmitted light and consequently the transparent body possesses the color produced by the combination of the unchecked vibrations, and intensity of color depends upon the amplitude of the vibrations. When a body absorbs all the colors of the spectrum except blue, but reflects that to the eye, we call it a blue body; when it absorbs all but green, we call it a green body; if it absorbs all the colors we call it black.

Thus arises color in glass, by the combination of the oxides of certain metals with the ingredients producing the glass, which become dissolved in the resultant product and possess the power to retard or extinguish certain of the vibrations of white light, and transmit corresponding colors. Thus colors may be produced simple or compound, by the use of a single oxide, a combination of oxides, or by a mixture of their products.

The nature of the metal, quantity present and state of oxidation, however, modify the power of extinction or absorption, which is illustrated by experiments with borax beads holding metallic oxides in solution and exposed to the action of a blow-pipe flame. Some metals, copper for instance, form two series of compounds, and give different colors to the bead when present in either the higher or lower state of oxidation, assuming a blue color while containing the copper in the cupric, and a red color when in the cuprous form. Iron in the oxidizing flame gives a deep orange color; manganese a violet; nickel a reddish brown; cobalt a purple blue; and chromium an emerald green or yellow. While in the reducing flame the orange of iron becomes a dull green; the violet of manganese disappears; the brown of nickel changes to a turbid grey, while the colors of cobalt and chromium remain unchanged. Opacity, or total extinction of light, is generally obtained by an infusible and insoluble excess present in the substance of the glass, by which all of the vibrations of light are absorbed. The black opacity is obtained by the excessive use of manganese and iron; and white opacity by a like use of arsenic, tin, calcium phosphate, fluor-spar, cryolite, etc.

Generally the coloring agents are incorporated directly with the batch. The former practice was however, that labor-entailed process, of first melting a pure flint batch, which was removed from the pot, cooled and pulverized; the coloring agents were then thoroughly mixed with the pulverized glass and it was remelted. This practice, for obvious reasons, has been

superseded by that of the direct incorporation of the coloring agents with the batch.

The Principal Coloring Agents Used in Glass.

Some oxides, as gold, silver, copper and iron, require special manipulation.

Gold.

Gold is used in glass to produce a red or so-called ruby color, which may be said to be difficult to obtain. Primarily in a ruby batch all ingredients must be of great purity, and the gold must be intimately incorporated with the batch. The temperature of the furnace must be sufficiently high, and the melt well regulated, as the color develops anywhere from red heat to point of fusion, and is aided in development in proportion to greater amount of gold used. Any batch producing salt water or "glass gall," must be avoided, as the gold will not distribute itself so long as these impurities are present. Two dangers are to be avoided; first the super-oxidation of the gold, which forms auric oxide, and does not color glass; second, the conversion of the oxide into metallic gold by reduction, which gives the glass the property of transmitting a blue color, while reflecting a dull brown. Hence it is very important to avoid an excessive use of reducing agents, and neutral agents must be added to the batch to regulate and limit the oxidation of the metal.

Gold distributes itself in the glass uniformly only at a very high temperature. Mueller claims that one part of gold will impart a red or ruby tint to 50,000 parts of glass, remain visible up to 100,000 parts, and entirely vanish at 200,000 parts.

Gold is added to the batch in the form of "purple of cassius," which is prepared (according to Pelletier) by dissolving 20 grammes of gold in 100 parts of "aqua regia," (20 parts nitric acid, and 80 parts of commercial hydrochloric acid,) aqua regia being the only true solvent of gold. Evaporate the solution to dryness and dissolve the residue in water; filter and dilute with about 7 or 8 deciliters (about 1½ pints) of water, and place in contact with tin filings. The liquid will then undergo a vigorous action and become brown, when a purple precipitate is thrown down, which is then washed and dried at a moderate heat; this constitutes "purple of cassius," and is composed about as follows:

Stannic acid	32.746
Protoxide of tin	14.618
Protoxide of gold	44.772
Moisture	7.864
	100.000

American colormakers, however, have dispensed with the use of tin, and simply dissolve the gold in equal parts of nitric and muriatic acids, and facilitate the dissolution by means of the sand bath, and as soon as dissolution is complete, the liquid holding the gold in solution is poured over the sand entering the batch, or on the batch itself, and thoroughly mixed with it.

Silver

The oxide of silver yields a color from light yellow to orange. The silver is not mixed with the batch in the ordinary method and then fused, as it is invariably reduced and is found at the bottom of the crucible. Silver added to the batch produces a pale yellow glass, and by attempting to intensify the color by increased quantity of silver, brings about an iridescent surface to the glass, instead of a deeper color, by that part of the silver over and above what is sufficient to saturate the glass, being superficially separated and producing other light effects. But if the chloride of silver be mixed with any convenient medium, say powdered clay, and applied to the surface of the glass with a brush as a pigment and the glass exposed to a moderate heat in a muffle, a yellow tint or stain will be imparted by penetration. By experiment Lemal demonstrated that by baking five minutes the color penetrated to a depth of 0.17 m, m; after one hour 0.34 m, m; after eighteen hours 1.6 m, m. By this means a lace pattern can be transferred to the glass by dipping the lace in a 0.001 per cent solution of silver nitrate, and then in potassium sulphide. The rate of penetration depends upon the nature of the glass and its atomic volume. But glass so stained should contain alumina to get a good effect.

The chloride of silver can be prepared by taking one part of nitric acid, and three parts boiling water, which forms ''aqua fortis'' and will dissolve one-third of its weight of silver before the acid is perfectly saturated. To precipitate the solution dilute it with five times its quantity of water, and add a portion of common salt; stir well continually. A white powder will be precipitated; decant the liquor, and continue adding boiling water until the water becomes quite insipid.

Silver is rarely introduced with the batch, because: First, it does not readily unite with oxygen; second, it loses its oxygen at a high temperature and becomes reduced to the metallic state, in which condition it exercises no coloring effect and is consequently worthless in that capacity.

Copper.

Copper forms two oxides; the peroxide or black oxide colors glass green; the sub-oxide or red oxide, red or ruby. Copper imparts its color at a fair red heat, and in making ruby glass especially, much that has been said regarding gold, in many instances applies to the use of copper; inasmuch as it must be incorporated thoroughly with the batch; the temperature of the furnace must be carefully regulated; ingredients generating ''glass gall'' must be avoided; and the oxide of copper must be associated with reducing agents of sufficient strength to prevent its super-oxidation.

Copper colors glass deeper than gold because of its greater fusibility. For the purpose of holding copper at its lower state oxidation, oxidizing agents are avoided, and reducing agents, as oxide of tin, iron scales, etc., are substituted.

To prepare oxide of copper, mix copper filings or small pieces of copper, with sulphur, in a crucible and burn until the whole is reduced to a cinder. When cool reduce to a powder (copper scales). Muspratt's method of procuring the sub-oxide of copper is to boil acetate of copper in four parts of sugar. The sugar assumes a portion of the oxygen from the cupric acetate, and it is reduced to the sub-oxide, which is precipitated as a brilliant red powder. Boil moderately about two hours, settle, decant liquid, wash and dry.

The use of commercial copper scales imparts a cheap blue color, which can be varied according to quantity of copper scales used.

Iron.

Iron colors glass green, yellow or red. The pure oxide of iron imparts an orange-red color to glass. For this purpose it may be prepared by heating the nitrate. The protoxide of iron imparts a green color, which however lacks brilliancy. Care must be taken to prevent the conversion of the protoxide into sequi-oxide, as the sequi-oxide colors glass orange.

An orange yellow can be obtained by combining iron, antimony and minium.

Manganese.

Manganese besides being a decolorizer yields, proportionate to quantity, a color varying from rose to violet, purple, brown and black. But manganese when exposed to intense and prolonged heat parts with a portion of its oxygen and becomes manganous oxide, and glass containing the oxide in this form is colorless.

Manganese used in connection with the oxides of copper and iron produces the color termed ''London smoke;'' (this same effect is produced by the combination of blue and amber colors).

Cobalt.

The oxide of cobalt yields a very rich color. It is very positive in its results, and is exceedingly easy to handle, and colors glass a deep, rich blue. A small amount of iron or copper oxide in connection with cobalt aids in preventing the hue from verging to violet, when used for intensity of color; while nickel or zinc brightens a cobalt blue.

Zaffre, an impure cobalt oxide, may be used, but there is no economy in its use.

Uranium.

The oxide of uranium produces the peculiar yellow color verging on green known as canary. It is too expensive except for the finest grades of yellow.

Chromium.

The oxide of chromium produces an emerald yellow, passing into a grass green. Used in excess the surplus remains disseminated through the glass in sparkling crystals.

Minium.

Minium, or oxide of lead, used in excess yields a pale yellow color.

Antimony.

Antimony sulphide roasted to a state of antimonious acid, and melted with from three to five per cent of undecomposed antimony sulphide produces a fine yellow.

Selenium.

Selenium is added directly to the ingredients in the pot, and imparts a rose tint to the glass. The depth and intensity of the tint depends upon the character of the glass to a certain extent, soft glass assuming more depth of color than hard glass. The tint however depends more especially upon the quantity of selenium used. By combining cadmium sulphide with the selenium, an orange-red color is the result, the intensity of the orange-yellow being proportionate with the quantity of cadmium sulphide, which should be mixed with the selenium before introducing it to the material to be colored.

Nickel.

Oxide of nickel imparts a bluish tint to potash glass; a hyacinth tinge to soda glass, and, used in excess, imparts a violet tint. The tints imparted by nickel are constant. Nickel is generally used in the form of nickelous oxide or protoxide of nickel, a powder of dull green color.

Zinc.

The oxide of zinc, as a rule, imparts a yellow color.

Carbon.

Carbon occurs in many forms, and is used for coloring glass from a straw color to a dark amber. Any carbon, or carbonaceous substance effects this purpose. It is generally used in the form of powdered charcoal, anthracite, cannel coal, coke, birch bark, burned animal hoofs, corn, oats, etc.

Calcium Phosphate.

Calcium phosphate, generally in the form of bone-ash, is used to impart opal color or opacity to glass. Bone-ash glass however, is brittle and difficult of fusion. Used in excess it increases liability to oxidation if exposed. Calcium phosphate used in moderate quantities imparts opalescence to the various colored glasses, which is developed in proportion to the amount of lime used, and temperature to which it is reheated.

Cryolite.

Cryolite is a brilliant mineral, sub-transparent to translucent substance found in Greenland, that is sometimes used in the manufacture of opal glass. Its composition is about as follows:

Aluminum	13.0
Sodium	32.8
Fluorine	54.2

It is fusible in the flame of a candle. The use of cryolite is objectionable on account of its vigorous attacks on the melting pot. When used it is proportioned about 14 pounds of cryolite to 100 pounds of sand.

Sodium Seleniate.

Seleniate of sodium is used to replace oxide of gold in the production of ruby colored glass. One to two pounds of seleniate of sodium to 1,000 pounds of sand, is recommended to produce a very fine red color.

Flour-Spar—Feldspar.

Fluor-Spar and feldspar (feldspar contains about 14 per cent of potash), are used principally as substitutes for cryolite, etc., in the manufacture of opal glass. While their action on the pot is even more vigorous than that of cryolite, yet glass in which they enter can be melted at a much lower temperature than cryolite glass. The proportion of these ingredients used is generally large—40 fluor-spar to 100 of sand; 20 feldspar to 100 of sand.

Tin Oxide.

Tin oxide imparts a white opacity to glass, but is expensive; hence its use has been to a certain extent discontinued.

Guano.

Guano seems to be the only substance which will impart a white opacity to glass, and yet be economical in cost and effect on pots. For these reasons foreign glassmakers have long since adopted it. Prof. Draper, of New York, gives the following analysis of Baker's Island and Jarvis' Island guano, which show the constituents to be be:

	Baker's Island.	Jarvis' Island.
Moisture	4.50	7.50
Organic matter	11.00	4.00
Soluble salts		2.50
Calcium sulphate	7.00	5.00
Calcium phosphate	76.80	81.00
Carbonates and silica	1.50	

Guano is always calcined before use to remove organic matter.

Borax.

Borax is sometimes used in colored glass to intensify the color.

Summary.

Taking into consideration the foregoing we summarize as follows:

Red is produced by manganese, oxide of iron, sub-oxide of copper, gold and sodium seleniate.

Blue is produced by cobalt, zaffre and copper scales.

Green is produced by protoxides of iron, peroxide of copper and oxide of chromium.

Black, by oxides of manganese, iron and cobalt.

Violet, by oxide of manganese.

Yellow, by oxide of uranium, antimony and silver.

Orange, by oxide of iron, antimony and minium combined.

White opal, by bone-ash, cryolite, oxide of tin or guano.

In making colors much must be determined by experiment, as no two glassmakers use precisely the same formulas, or work under similar conditions; and all effects must be determined by such circumstances as crude materials, oxides, furnaces, fuels, pots, etc.

We have assumed to outline in the preceding pages, the basis of the fixed and more prominent colors. Other colors may be produced indefinitely by blending different colors, hues and densities into new colors modified in tone and intensity. It is perfectly reasonable to suppose, that as the artist blends his pigments, so may a glassmaker blend his batches, to a certain extent of course, in the production of compound colors. Good judgment and ingenuity figure largely in this particular.

If a color is intense it may be toned down by the addition of clean flint glass cullet of the same composition, as the foundation of the average colored glass is simply a good crystal flint batch to which the oxides productive of the different colors have been added. The intensity of a color varies in proportion with the quantity of the oxide used, and it is very important that the materials composing the entire batch are as pure as possible. Pellat in his "Curiosities of Glassmaking," recommends for a good flint batch:

Carbonate of potash	100
Red lead, or litharge	200
Sand	300
Saltpetre	14 to 28
Oxide of manganese	¼ to ⅜

The American practice in many instances is to substitute an equivalent of soda for potash, except when lead is used.

As lead glass assumes a finer, fuller color it is preferable to lime glass in making fine colors, besides a smaller amount of coloring matter can be used. But while lime glass requires a larger quantity of the oxides, the addition of a small quantity of lead enhances the color and improves the quality of the glass.

The use of salt cake is never advised in the finer grades of colored glass, as the carbon required to remove the salt water and like impurities would radically impair the coloring power of the oxides; hence it is advisable to not add the oxides, when salt water does occur, until it has been thoroughly removed, and then add them to the fluid glass. In such cases it is best to mix the coloring agents with pulverized glass, and thus add them to the metal. As the pulverized glass melts it envelops the oxides, prevents their evaporation, decreases their liability of reduction to the metallic state, and holds them in suspension in the glass, as, on account of their greater specific gravity, they have a tendency to sink to the bottom of the pot. This is especially so where they have been added to the fluid glass instead of being mixed with the batch.

Red Glass. (Ruby.)

Gold Red.

The use of a rich lead batch is recommended, to which add one ounce of gold to every sixty pounds of batch. This is the usual American practice. Pellat recommends the use of four ounces of gold to every six hundred (600) pounds of batch. Kohn recommends 0.115 kilograms of gold to every 100 kilograms of sand.

When a pot of metal is plain it should be "worked out" at once, and the color developed in a hot lehr. If the metal turns muddy or thick while working it, ladle it into clean water.

Recipes for Gold Red.

—1—

Sand	62 lbs	Antimony	6 oz
Lead	76 lbs	Manganese	3 oz
Nitre	22 lbs	Gold	1 oz to 80 lbs batch

—2—

Sand	56 lbs	Antimony	4 oz
Lead	63 lbs	Manganese	2 oz
Nitre	18 lbs	Gold	1 oz to 10½ drams

—3—

Sand	60 lbs	Nitre	7 lbs
Lead	34 lbs	Arsenic	1 oz
Pearl ash	25 lbs	Gold	1 0z

Note—Must be filled, melted, ladled and refilled three times, and has the appearance of dirty flint until after annealing.

—4—

Sand	32 lbs	White oxide of antimony	2 oz
Lead	36 lbs	Manganese	1 oz
Nitre	16 lbs	Gold	1 oz

—5—

Sand	12 lbs	Pearl ash	1 lb
Lead	14 lbs	White oxide of antimony	¾ oz
Nitre	5 lbs	Manganese	½ oz
Gold	½ oz		

—5—

Sand	16 lbs	White oxide of antimony	1 oz
Lead	18 lbs	Manganese	¾ oz
Nitre	8 lbs	Prepared gold	½ oz

—7—

Sand	100 lbs	Oxide of tin	13 oz
Lead	80 lbs	White oxide of antimony	13 oz
Potash	32 lbs	Red oxide of iron	2 oz
Saltpetre	4 lbs	Manganese	13½ oz
Regulus antimony	1¾ lbs	Gold	1½ oz

—8—

Sand	102 lbs	Oxide of tin	13 oz
Potash	32 lbs	Red oxide of iron	2 oz
Lead	80 lbs	Manganese	12 oz
Nitre	4 lbs	Powdered slate	½ oz
Black oxide of antimony	1¾ lbs	Gold	1½ oz

Belgian; rose-red.

—9—

Sand	100	Tin	0.4 dissolved in aqua regia
Potash	32	Gold	0.04 dissolved in aqua regia
Red lead	40	Mix solution with three or four quarts of water and moisten the sand with it.	
Nitrate of potash	15		
Borax	15		

To retain rose-red, avoid an excess of lead, which has a tendency to lead the color to violet. Per-oxide of tin adds warmth to color.

Copper Red.

Copper reds are more difficult to make than gold reds. The reduction of the copper must not be carried beyond a certain limit, as the copper will return to the metallic state and give the glass, instead of a ruby color, a spangled effect; hence it often happens when trying to obtain copper reds the so-called ad-venturin glass is the result, and vice versa. Again, when the reduction is carried too far the glass assumes an opaqueness that resembles a coral or sealing wax red color.

Copper Red Recipes.

—1—

Sand	100	Cullet	100
Carbonate of sodium	28	Oxide of copper	4
Slacked lime	24	Oxide of iron	4
Lead	8	Nitrate of potassium	8

—2—

Sand	100	Oxide of copper	7
Soda	38	Oxide of tin	7
Lead	66	Nitrate of potassium	10
Oxide of iron	4		

Bohemian.

—3—

Copper cullet	15 lbs.

When melted add copper calcined to redness, 4 to 6 oz; let it settle and add powdered red tartar; let all refine, and then work out and anneal until the color assumes sufficient depth.

Wax Red.

—4—

Flint batch	2 lbs.	Tartar salts	2 oz.
Calcined copper	4 oz.	Oxide of iron	½ oz.

—5—

Sand	9	Pearl ash	3
Lead	6	Raw brass	1
Crocus martis	12 oz.		

—6—

Flint batch	30	Brown glass metal	30
Calcined copper	1		

Belgian for Flashing.

—7—

Sand	100	Borax	12
Potash	32	Carbonate of calcium	10
Red lead	40	Peroxide of copper	2
Nitrate of potassium	12	Peroxide of tin	2
Iron filings	0.5		

Henrivaux.

—8—

Sand	100
Carbonate of sodium	75
Lime	20
Equal parts of copper scales and sulphate of iron heated to red heat	10
Stannic acid	10

Melt, cast, grind to fragments and add per 100 parts:

Sand	80
Carbonate of sodium	30
Lime	14

Cast and grind as before, and add 35 parts of sand and remelt.

Bontemps.

—9—

Sand	25
Red lead	50
Oxide of copper	1.2
Stannic acid	3

Melt, stir cast, grind and remelt three successive times. At second color is light yellow, at third the color is an orange yellow.

After third casting mix with 25 parts of crystal glass composed as follows:

Sand	100
Carbonate of potassium	36
Lime	18
Red lead	3

These 25 parts of cullet are melted with above. Add 30 to 40 grains of tartar or tin chips and remelt.

Amethyst Glass.

Flint batch	112	Manganese	8 oz
Crude antimony	1 oz		

BLUE GLASS RECIPES.

Deep Azure.

—1—

Sand	40	Nitre	15
Lead	50	Arsenic	3
Zaffre	4 oz		

—2—

Flint batch	600	Zaffre	9
Flint cullet	600	Manganese	1

—3—

Flint batch	560	Zaffre	9

—4—

Flint batch	600	Zaffre	6
Manganese	3		

—5—

Flint batch	800	Zaffre	2
Manganese	1½		

Deep Opaque.

Sand	49	Phosphate of calcium	9
Lead	39	Arsenic	1
Nitre	11	Zaffre	8 oz
Brass filings	3 oz		

—7—

Sand	300	Nitre	50
Lead	200	Borax	4
Soda	100	Manganese	8
Oxide of cobalt	3		

—8—

Sand	260	Nitre	20
Lead	212	Zaffre	4
Ash	85	Manganese	1¼

—9—

Flint batch	120	Nitre	10
Cullet	220	Zaffre	3
Manganese	1		

—10—

Flint batch	200	Nitre	6
Flint cullet	200	Zaffre	2

—11—

Flint batch	250	Oxide of nickel	2

—12—

Flint batch	112	Blue cullet	112
Zaffre	1		

Soft.

—13—

Sand	44	Nitre	8
Lead	44	Zaffre	2½
Ash	20	Manganese	4

Opaque Sky Blue

—14—

Opal batch	28	Phosphate of calcium	1
Arsenic	4 oz	Zaffre	1½ oz
Calcined brass	¾ oz		

—15—

Sand	40	Nitre	15
Lead	50	Arsenic	5
Zaffre	3 oz		

Waterloo Blue.

—16—

Flint batch	40	Cullet	40
Zaffre	4 oz		

—17—

Sand	1000	Manganese	10 oz
Soda	360	Arsenic	10 oz
Lime	125	Cobalt	10 oz

Cheap Blue

—18—

Sand	100	Nitre	7
Soda	35	Manganese	2½ oz
Lime	18	Arsenic	2½ oz
Cobalt	1 oz		

—19—

Window glass	100	Zaffre	1
Sulphate of sodium	6	Manganese	½

Blue-Green

—20—

Flint batch	112	Black oxide of copper	3 oz
Oxide of iron	3 oz		

—21—

Sand	100	Oxide of cobalt	½
Potash	25	Salt	2
Borax	4	Arsenic	½
Slacked lime	12	Blue cullet	100

Blue Sheet

—22—

Sand	100	Zaffre	½
Soda	35	Arsenic	1
Lime	10	Oxide of zinc	1
Bone dust	10		

For Casing.

—23—

Sand	100	Bi-carbonate of sodium	50
Lead	1	Cobalt	1
Nitrate of sodium	10	Manganese	½
Arsenic	½	Cullet	100

For Casing.

—24—

Flint batch to be cased	100	Best cobalt	1

Henrivaux.

—25—

Sand	100	Oxide of cobalt	0.400
Soda	36	Oxide of copper	7
Carbonate of calcium	25	Saltpetre	6
Lead	10	Flint cullet	200

Belgian: Light.

—26—

Sand	100	Black oxide of copper	0.01
Soda	32	Black oxide of cobalt	0.04
Carbonate of calcium	24	Borax	1
Charcoal	2.5		

Belgian: Dark.

—27—

Sand	100	Black oxide of copper	1.5
Soda	32	Copper sulphate	1.5
Carbonate of calcium	24	Black oxide of cobalt	0.15
Charcoal	2.5	Borax	1

Belgian for Flashing.

—28—

Sand	100	Oxide of copper	4
Soda	32	Oxide of cobalt	0.3
Carbonate of calcium	24	Borax	5
Charcoal	2.5		

Green Glass Recipes.

—1—

Flint batch	500	Copper scales	22½

—2—

Flint batch	1000	Copper scales	15
Red ochre	14		

Blue-Green.

—3—

Flint batch	500 lbs	Calcined copper	7 lbs
Iron scales powdered, washed and dried	8 oz		

Light Blue-Green.

—4—

Flint batch	108 lbs	Peroxide of iron	3 oz
Carbonate of copper	2 lbs 4 oz		

Dark Green.

—5—

Flint batch	100 lbs	Black oxide of copper	1 lb
Crocus martis	12 oz		

Light Yellow-Green.

—6—

Flint batch	28	Bi-chromate of potassium	2

Blue-Green.

—7—

Flint batch	224	Brass filings	8

Light Emerald-Green.

—8—

Sand	120	Pearl ash	40
Lead	60	Nitre	20
Iron filings	1		

Green for Muffs.

—9—

Flint batch	380	Flint cullet	320
Nitre	10	Brass filings	30
Manganese	2		

Emerald Green.

—10—

Flint batch	280	Iron filings	2 lbs 8 oz
Flint cullet	250	Borax	2
Antimony	8 oz		

Light Green for Muffs.

—11—

Flint batch	100 lbs	Iron filings	4 oz
Borax	6 oz		

Emerald Green.

—12—

Sand	100 lbs	Nitre	7 lbs
Soda	35 lbs	Manganese	2½ oz
Lime	18 lbs	Arsenic	2½ oz
Copper scales	6 oz		

Yellow-Green.

—13—

Flint batch	50 lbs	Yellow arsenic	3 lbs 2 oz
Crocus martis	3 lbs 2 oz	Brass filings	1 lb 9 oz

Green-Yellow.

—14—

Flint batch	260	Green yellow cullet	550
Flint cullet	100	Brass	34
Iron	16		

Saxon Green.

—15—

Sand	135	Nitre	36
Lead	100	Oxide of copper	6

Opaque Green.

—16—

Sand	18 lbs	Arsenic	3
Nitre	14 lbs	Brass filings	3 oz
Oxide of copper	2 oz		

Emerald-Green.

—17—

Flint batch	126 lbs	Iron filings	11 oz
Oxide of copper	5 oz		

Bohemian Aqua-Marine.

—18—

Sand	100	Oxide of copper	8
Soda	38	Oxide of iron	4
Lime	12	Salt	3
Arsenic	⅛		

Yellowish-Green Sheet Glass.

—19—

Sand	100	Bone ash	10
Soda	38	Yellow or red chromate of potassium	3
Carbonate of calcium	25		

Plain cullet	100		

Chromate dissolved and poured over the sand.

Pomona.

—20—

Sand	100	Sulphate of copper	2-3
Soda	35	Arsenic	1-8
Lime	22	Uranium	1

Green for Casting.

—21—

Sand	100	Nitrate of sodium	3
Potash	38	Oxide of copper	8
Lead	58	Oxide of iron	3
Bi-carbonate of potassium	1		

Bontemps Yellow Tinted.

—22—

Sand	100	Nitrate of potassium	7
Carbonate of sodium	33	Oxide of iron	3
Chalk	20	Oxide of copper	5
Bi-chromate of potassium	1.4		

Belgian Green: Yellowish.

—23—

Sand	100	Charcoal	2.5
Soda	32	Black oxide of copper	.8
Carbonate of calcium	24	Bi-chromate of potassium	1
Borax	1		

Belgian Bluish Green.

—24—

Sand	100	Black oxide of copper	1
Soda	32	Bi-chromate of potassium	0.5
Carbonate of calcium	24	Borax	1
Charcoal	2.5	Smalt	1

Belgian Dark Green.

—25—

Sand	100	Black oxide of copper	1.5
Soda	32	Bi-chromate of potassium	1
Carbonate of calcium	24	Borax	1
Charcoal	2.5	Smalt	0.1
Red oxide of iron (crocus martis)	1		

Oriental Green.

—26—

Sand	36 lbs	Nitre	16 lbs
Lead	29 lbs	Oxide of uranium	9 oz
Carbonate of copper	2½ oz		

Olive Green.

—27—

Flint batch	112	Red ochre	4
Brass	2		

Pea Blossom Green.

—28—

Flint batch	100	Zaffre	1 lb 8 oz
Manganese	12 oz		

Note.—Uranium imparts a greenish fluorescence to glass. Copper-green should always be melted in covered pots. The use of chromium oxides has been abandoned, and red and yellow chromates of potassium have been substituted, and should be used in a finely pulverized condition.

Turquois Glass Recipes.

—1—

Sand	500	Nitre	64
Lead	400	Phosphate of calcium	90
Pearl ash	160	Arsenic	15
Calcined brass	15		

—2—

Sand	24 lbs	Phosphate of calcium	3 lbs 12 oz
Lead	19 lbs	Arsenic	1 lb 4 oz
Pearl ash	6 lbs	Zaffre	3 lbs 4 oz

—3—

Sand	50 lbs	Nitre	6 oz
Lead	50 lbs	Phosphate of calcium	9 oz
Pearl ash	16 lbs	Arsenic	1 lb 8 oz
Brass filings	1 lb 8 oz		

—4—

Flint batch	5 lbs	Green cullet	3 lbs
Blue cullet	5 lbs	Enamel white	1 oz

—5—

Sand	160 lbs	Pearl ash	28 lbs
Lead	80 lbs	Phosphate of calcium	18 lbs
Nitre	28 lbs	Arsenic	3 lbs
Brass filings	1 lb 8 oz		

Very Good.

—6—

Sand	100 lbs	Pearl ash	40 lbs
Lead	80 lbs	Phosphate of calcium	18 lbs
Nitre	20 lbs	Arsenic	3 lbs
Brass filings	1 lb 8 oz		

Note.—Turquois batches must be thoroughly mixed. Add sulphate of copper to batch to raise color; phosphate of calcium to lower color.

Black Glass Recipes.

Common.

—1—

Green cullet	100	Manganese	8
Soda	38	Oxide of iron	6
Lime	18	Pulverized coke	4
Aresnic	2		

Fine.

—2—

Sand	100	Oxide of copper	10
Potash	36	Oxide of iron	10
Lime	13	Manganese	10
Zaffre	10		

—3—

Sand	100	Oxide of copper	4
Potash	15	Oxide of iron	4
Soda	24	Manganese	5
Lime	18	Zaffre	2

Belgian.

—4—

Sand	100	Black oxide of copper	3
Soda	31	Manganese	4
Carbonate of calcium	24	Smalt	4-10
Charcoal	2.5	Peroxide of nickel	3-10
Borax	1		

Yellow-Black.

—5—

Sand	100	Charcoal	2.5
Soda	32	Manganese	2
Carbonate of calcium	25		

—6—

Flint batch	560	Manganese	20

—7—

Flint batch	100	Zaffre	10
Manganese	7½	Calcined iron	6 oz 2 drams

—8—

Flint glass	200	Black cullet	100
Flint chest cullet	100	Manganese	50

—9—

Flint batch	600	Manganese	40
Black cullet	700	Oxide of iron	40

—10—

Flint batch	112	Oxide of iron	7
Manganese	12	Zaffre	4 oz

—11—

Window glass	1500	Manganese	64
Nitrate of sodium	75	Zaffre	1

A grey glass is obtained by neutralizing the violet color imparted by manganese with the oxides of iron and copper. The same effect may be obtained by the use of oxide of nickel.

Brown Glass Recipes.

—1—

Flint batch	30	Red lead	42
Manganese	12½		

Dark.

—2—

Flint batch	53	Manganese	20
Flint cullet	50	Zaffre	2

Amber Glass Recipes.

—1—

Flint cullet	12 lbs	Nitre	8 oz
Lead	4 lbs	Tin ash	2 oz
Sand	2 lbs	Oxide of silver	3 dr
Oxide of copper	½ oz		

—2—

Flint batch	56	Nitre	16
Lead	64	Amber	2

—3—

Flint batch	112	Manganese	4
Red ochre	20	Arsenic	1

—4—

Flint batch	30 lbs	Red oxide of iron	5 oz
Flint cullet	50 lbs	Manganese	8 oz
Antimony	1 oz		

—5—

Flint batch	112	Crocus martis	6
Manganese	2		

Rich Color.

—6—

Flint batch	112	Peroxide of iron	5
Manganese	1		

Good.

—7—

Amber cullet	448	Red oxide of iron	63
Flint cullet	784	Manganese	14
Flint batch	124	Arsenic	1

Rich Dark.

—8—

Sand	12 lbs	Nitre	2 lbs
Lead	10 lbs	Oxide of iron	2 lbs
Pearl ash	4 lbs	Manganese	4 oz

—9—

Flint batch	20 lbs	Yellow aresnic	10 oz
Crocus martis	10 oz	Coal dust	7 oz

Western Practice.

—10—

Sand	900	Lime	120
Soda	340	Cannel coal	6
Sulphur	2		

—11—

Flint batch	100 lbs	Coal dust	1 lb 1 oz
Crocus martis	3 lbs 2 oz	Yellow aresnic	1 lb 9 oz

—12—

Sand	100 lbs	Lime	28 lbs
Soda	40 lbs	Fine salt	10 lbs 15 oz
Pulverized charcoal	3 lbs 15 oz		

Purple Glass Recipes.

—1—

Flint batch	100 lbs	Manganese	10 oz
Zaffre	5 oz		

—2—

Flint batch	100 lbs	Manganese	16 oz
Zaffre	1¼ oz		

—3—

Flint batch	560 lbs	Manganese	12 lbs
Cullet	50 lbs	Antimony	1 oz

—4—

Flint batch	220	Borax	6
Manganese	2	Cullet	260

—5—

Flint batch	560	Manganese	12
Arsenic	1		

—6—

Broken window glass	1000	Manganese	32
Nitrate of sodium	50	Zaffre	4 oz

Note.—The commonest kind of material will do for purple glass; even black, or window glass, fluxed with nitrate of sodium.

Violet Glass Recipes.

—1—

Flint batch	84 lbs	Calcined copper	5 lbs 8 oz
Strong smalt	4 lbs 6 oz	Antimony	6 oz

—2—

Flint batch	100	Calcined brass	1
Zaffre	1½		

—3—

Sand	56	Nitre	4
Lead	28	Calcined copper	4
Pearl ash	14	Strong smalt	3
Antimony	2		

Opaque Violet.

—4—

Sand	40 lbs	Nitre	15 lbs
Lead	45 lbs	Arsenic	2 lbs
Oxide of nickel	7 oz		

Henrivaux.

—5—

Sand	100	Carbonate of calcium	90
Soda	100	Nitrate of potassium	90
Potash	20	Manganese	22

Lead	90	Nitrate of sodium	12
Cullet	90		

Violet Sheet.

—6—

Sand	100	Slacked lime	15
Soda	35	Manganese	10
Lead	2	Saltpetre	2
Ground glass	100		

Belgian.

—7—

Sand	100	Charcoal	2.5
Soda	30	Manganese	3
Limestone	25	Smalt	0.1
Borax	1		

For Flashing.

—8—

Sand	100	Charcoal	2.5
Soda	30	Manganese	6
Limestone	25	Oxide of cobalt	0.2
Borax	1		

White Glass Recipes.

White Enamel.

—1—

Sand	100 lbs	Soda	70 lbs
Lead	100 lbs	Arsenic	16 lbs
Antimony	8 oz		

White Enamel.

—2—

Sand	300 lbs	Arsenic	24 lbs
Lead	300 lbs	Alabaster or chalk	8 lbs
Nitrate of sodium	25 lbs	Manganese	3 oz
Antimony	2 oz		

White Enamel.

—3—

Sand	120 lbs	Nitrate of sodium	40 lbs
Lead	130 lbs	Arsenic	15 lbs
Antimony	6 oz		

White Enamel.

—4—

Sand	15 lbs	Arsenic	1½ lbs
Lead	16 lbs	Manganese	1 oz
Nitrate of sodium	4 lbs	Antimony	1 oz

White Enamel.

—5—

Sand	100 lbs	Lead	120 lbs
Nitrate of sodium	24 lbs	Arsenic	10 lbs
Antimony	6 oz		

White Enamel.

—6—

Sand	37	Pearl ash	1
Lead	28	Arsenic	4
Nitre	24	Sulphate of calcium	1
Antimony	1		

White Enamel.

—7—

Sand	60 lbs	Pearl ash	10 lbs
Lead	48 lbs	Arsenic	6 lbs
Nitre	29 lbs	Phosphate of calcium	3 lbs
Antimony	2 oz		

White Enamel.

—8—

Sand	336 lbs	Arsenic	24 lbs
Lead	336 lbs	Chalk	8 lbs
Nitre	20 lbs	Antimony	2 lbs
Manganese	3 oz		

White Enamel.

—9—

Sand	180	Arsenic	12
Lead	160	Antimony	4
Nitre	20		

White Enamel.

—10—

Sand	112	Arsenic	8
Lead	112	Antimony	¾
Nitre	20	Manganese	1

Note.—To every pound common flint batch in Nos. 6, 7, 8, 9 and 10, add: Arsenic 1 oz., chalk ¼ lb., lead 1 oz.

Alabaster.

—11—

Sand	20 lbs	Arsenic	1¼ oz
Potash	10 lbs	Manganese	4 oz
Quicklime	4 lbs 2¼ oz	Nitre	6 lbs
Phosphate of calcium	4 oz		

Alabaster.

—12—

Sand	20 lbs	Quicklime	3 lbs 9 oz
Potash	6 lbs	Arsenic	1 oz
Phosphate of calcium	1½ to 3 lbs		

Alabaster.

—13—

Sand	40 lbs	Arsenic	2 oz
Potash	44 lbs	Manganese	2 oz
Quicklime	9 lbs	Nitre	2 oz
Phosphate of calcium	4 lbs 8 oz		

Opal.

—14—

Flint batch	500	Arsenic	4
Bone ash	60	Borax	15

—15—

Flint batch	112 lbs	Soda	30 lbs
Lead	84 lbs	Nitre	32 lbs
Bone ash	23 lbs	Arsenic	2 lbs
Antimony	2 oz	Manganese	2 oz

—16—

Sand	40	Nitre	15
Lead	45	Arsenic	3½

—17—

Sand	114 lbs	Nitrate of sodium	30 lbs
Lead	75 lbs	Sulphate of calcium	16 lbs
Soda	30 lbs	Arsenic	6 lbs
Antimony	3 oz		

—18—

Sand	204	Nitrate of sodium	140
Lead	172	Arsenic	12
Antimony	¼		

—19—

Sand	20	Nitrate of sodium	8
Lead	25	Arsenic	1¾

—20—

Sand	1800	Lead	160
Nitrate of sodium	10	Arsenic	12

—21—

Flint batch	400	Burnt bones	25
Arsenic	7	Zaffre	1 oz

Note—To every pound flint batch Nos. 21 and 22 add: Arsenic ½ oz. and nitre ½ oz.

—22—

Sand	100	Phosphate of calcium	20
Lead	80	Arsenic	3
Nitrate of sodium	30	Antimony	4 oz
Potash	28		

Will Turn in Working.

—23—

Sand	90	Arsenic	2
Lead	60	Antimony	⅛
Phosphate of calcium	15	Potash	30

Will Turn in Working.

—24—

Sand	56	Arsenic	1¾
Lead	44	Antimony	¼
Phosphate of calcium	10	Potash	24

Will Turn Without Cooling.

—25—

Flint batch	112	Phosphate of calcium	10
Lead	4	Arsenic	1
Antimony	1-32		

—26—

Sand	49	Nitre	11
Lead	39	Phosphate of calcium	9
Arsenic	1 lb 8 oz		

Note.—For turquois add 10 ounces calcined brass.

Bright Opal.

—27—

Sand	100	Fluor-spar	25
Lead	38	Potash	19
Bi-carbonate of potassium	10	Borax	1
Feldspar	35	Manganese	⅛

Bright Opal.

—28—

Sand	100	Flour-spar	22
Soda	35	Feldspar	38
Lime	10	Nitre	4
Oxide of tin	5	Manganese	⅛

German Lead Opal.

—29—

Sand	100	Cryolite	14
Soda	10	Lead	6
Feldspar	13	Saltpetre	3

German Without Lead.

—30—

Sand	100	Bone ash	18
Slacked lime	16	Soda	45
Arsenic	3		

Bontemps' French Opal.

—31—

Sand	100	Bone ash	14
Lead	120	Borax	4
Potash	30	Oxide of zinc	9
Arsenic	4		

Lime Opal.

—32—

Sand	100	Nitre	9
Soda	33	Feldspar	15
Lime	8	Arsenic	6
Bone	5		

Note.—Oxide of tin is seldom used. Lead increases smoothness and luster. Bone ash glass on account of brittleness and hardness endures a high temperature without losing shape; hence is suitable for decorating in the muffle. Opalescence is imparted to glass by the use of less phosphate of calcium than is necessary to render it opaque when first taken from the pot; and as opal glass is easily colored with the various metallic oxides, opalescence may be imparted by reheating the glass. A glass, colored or crystal, may be made opalescent, semi-opaque or opaque in proportion to amount of phosphate of calcium used and amount of heat to which the glass is exposed while being manipulated. The coloring power of the oxides is modified by opalescence, and the tints may be made to vary in intensity according to the amount of heat to which they are exposed.

Yellow Glass Recipes.

Yellow Sheet.

—1—

Sand	100	Charcoal	4
Soda	45	Arsenic	1
Carbonate of calcium	40		

French Yellow.

—2—

Sand	100	Lime	25
Potash	40	Sulphur	1 1-5
Arsenic	⅛		

—3—

Flint batch	150 lbs	Crocus martis	2 lbs 5½ oz

—4—

Flint batch	100 lbs	Crocus martis	6¼ oz

Soft Yellow.

—5—

Flint batch	3 lbs	Naples yellow	1 lb
Red lead	6 oz		

Green Yellow.

—6—

Flint batch	16 lbs	Crocus martis	48 grains
Lead	16 lbs	If too green increase the quantity of crocus martis.	
Oxide of copper	6 oz		

Gold Yellow.

—7—

Flint batch	50	Purified tartar	1
Flint cullet	50	Manganese	1

Victoria Yellow.

—8—

Flint batch	350	Oxide of uranium	2½

Claret Yellow.

—9—

Flint batch	100	Red oxide of iron	7 oz

Yellow for Lamps.

—10—

Flint batch	112	Manganese	2½
Arsenic	2¾	Oxide of iron	15

Victoria Yellow or Topaz.

——11——

Sand	125	Potash	37
Lead	52	Nitre	7
Uranium	2		

Note—To impart to any of the above yellows a green tinge, shading green one way and yellow the other way, add carbonate of copper 1 to 5 ounces.

Gold and Silver Yellow—Fachblatt.

——12——

Pure quartz sand	74 kilogrammes
Potash made up with molasses	6¾ kilogrammes
Saltpeter	15 kilogrammes
Red lead	19 kilogrammes
Crystallized (humid) borax	30 kilogrammes

Silver dissolved in nitric acid 27 and 45 grammes.
Gold dissolved in aqua regia 5 franc piece.

Belgian Yellow for Flashing.

——13——

Sand	100	Borax	10
Potash	32	Saltpetre	10
Red lead	20	Carbonate of calcium	12
Chloride of silver	0.3		

Artificial Gems.

The ancients secretly prosecuted the manufacture of artificial gems, but in the decline of the art of glass the secrets were lost. Joseph Strasser, a Viennese jeweler, rediscovered the ancient method of imitating precious stones; hence the glass which forms the base of all imitations is called "Strass." This is a glass very rich in lead, to which the coloring materials are added. Lead ranks first in importance by imparting the great specific gravity and refractive power essential in imitating the products of nature. In making this glass the greatest care is necessary; all ingredients must be chemically pure to obtain good results, and be carefully pulverized and thoroughly mixed. Specially manufactured pots are used, and in Austria and France, where a specialty of this glass is made, the pots are about one-quarter of an inch thick, and hold about six gallons, and are highly burned and glazed with loam, which makes the clay hard and dense. The melting temperature varies between 1,000° and 1,500° centigrade. Great care is necessary during the melt. After the glass has been carefully melted it is allowed to cool very slowly and annealed in the pots. Profitable results in working up the glass are only obtained by careful cooling, which insures homogeneity and avoids disintegrating by cracks, splintering, etc. When cool the glass and pots are separated with hammer and chisel, and the glass reworked into gems.

Recipes for Aritificial Gems.

Venetian Adventurin—Fremy-Clemandot.

——1——

Pulverized lead flint	300 parts	Iron scales	80 parts
Copper scales	40 parts		

Spangled Glass—American Practice.

——2——

Flint batch (rich) melted until plain. Add copper filings; stir thoroughly; reheat until the glass has settled and all air expelled. The reheating requires both tact and care to be successful.

Yellow Adventurin.

——3——

Plate glass	2000	Iron scales	125
Nitrate of potash	200	Peroxide of iron	60

When fused add 38 grains of iron filings, stir, and cool very slowly.

Yellow Adventurin.

——4——

White sand	250	Calcined iron scales	112
Carbonate of sodium	100	Copper scales	23
Carbonate of calcium	50		

Green Adventurin.

——5——

White sand	250	Carbonate of calcium	50
Carbonate of sodium	100	Bi-chromate of potassium	40

Strass'—Donald-Wieland.

——6——

Rock crystal	300	Arsenious acid	1
Slacked lime	163	Red lead	470
Calcined borax	22		

Strass'—Donault-Wieland.

——7——

White sand	300	Arsenious acid	1
Slacked lime	96	White lead	514
Calcined borax	27		

Strass' Bastenaire.

——8——

Sand	100	Borax	20
Lead	40	Saltpetre	12
Potash	24	Manganese	.04

Opal—Bastenaire.

—9—

Sand	25	Saltpetre	2
Lead	25	Oxide of tin	16
Potash	10		

Topaz—Donault-Wieland.

—10—

White strass	1000	Purple of cassius	1
Clear yellowish orange red glass of antimony	40		

Emerald.

—11—

White colorless strass	1000	Oxide of chromium	0.2
Pure oxide of copper	8		

Amethyst.

—12—

Colorless strass	1000	Oxide of cobalt	5
Oxide of manganese	8	Purple of cassius	0.2

Garnet.

—13—

Colorless strass	1000	Purple of cassius	4
Glass of antimony	500	Oxide of manganese	4

Imitation Ruby.

—14—

Strass	80 parts	Oxide of manganese	2 parts

Paste Resembling the Diamond.

—15—

White sand	900 parts	Nitre	300 parts
Red lead	600 parts	Arsenic	50 parts
Pearl ash	450 parts	Manganese	½ part

Imitation Gold.

—16—

Platinum	16 parts	Zinc	1 part
Copper	7 parts		

Put in a crucible with powdered charcoal, or:

Platinum	4 oz.	Copper	1 oz
Silver	3 oz.		

Enamels.

Enamels constitute easily-fused glasses, colored by the same metallic oxides as the colored glasses. The art of enameling lent a charm to the works of past ages, but it has fallen into disuse.

Lead predominates largely in enamels, which are generally a silicate of lead, potash and soda, mixed with tin and antimony salts of the same elements; the silicates are also sometimes mixed with the borates. The object of the enamel applied to glass is to convey the idea of a metallic lustre, but owing to the low fusing point of glass the ordinary metallic lustres applied thereto have lacked stability; the low temperature at which they are fired, on account of the fusibility of the glass, is insufficient to convert the boracic acid and silica, for instance, into stable compounds of a definite resistance. G. Alefeld suggests the conversion of the metallic oxides into a durable condition by adding to the lustres before use, substances that will transform the oxides into saturated and stable compounds, as phosphates, titanates, molybdates, tungstates or vanadates, which will be applicable to even a very fusible ground.

Cost of Glass Per Pound.

When the materials constituting the different varieties of glass have been melted into glass and it is ready to be worked the cost per pound of the different varieties does not vary greatly, possibly excepting lead-flint. The cost of the melted glass in the pot averages from 10 to 20 per cent of the cost of the finished product ready to ship, and it is the labor required to put the glass into commercial forms that entails the cost. Even a large portion of the above 10 to 20 per cent involves considerable labor in the form of mixer, teazer, furnace builder, potmaker, etc. The following approximates estimates of cost per pound were computed in 1892:

Flint Bottles.

Sand	.000503
Soda ash	.004510
Lime	.000269
Glass	.000039
Manganese	.000069
Nitrate of soda	.000896
Arsenic	.000088
Other materials	.000018
All labor except blowing	.007998
Officials and clerks	.002993
Supplies and repairs	.001734
Fuel	.004866
Taxes	.000334
Total	.024317

Lamp Chimneys.

Sand	.000358
Soda ash	.001009
Potash	.003300
Lime	.000018
Lead	.007407
Glass	.003181
Other materials	.000348
All labor except skilled and boys	.011359
Officials and clerks	.002816
Supplies and repairs	.002010
Fuel	.006127
Taxes	.000206
Total	.038139

Green Glass.

Sand	.000721
Soda ash	.003747
Burnt lime or limestone	.000196
Glass	.00872

Other materials	.000005
All labor except blowing	.005739
Officials and clerks	.000390
Supplies and repairs	.000537
Fuel	.001033
Taxes	.000027
Total	.013267

Recipes for Silvering Glass.

Liquid Foil for Silvering.

—1—

Lead	1 part
Tin	1 part
Bismuth	1 part

Melt, and just before it sets add mercury....................10 parts; pour into globe and turn rapidly.

—2—

Nitrate of silver	1 oz	Liquid ammonia	1 oz
Distilled water	3 oz	Alcohol	3 oz

Let mixture stand one hour and filter. To each ounce of above solution add one-fourth ounce of grape sugar, dissolved in equal quantities of water and alcohol. The surface to be silvered is covered with liquid and heated to a temperature of 160° F, until the deposit of silver is complete; when dry give the surface a covering of mastic varnish.

—3—

Partly dissolve one ounce of nitrate of silver in one-half pint of distilled water; when dissolved and stirred well, pour off about one and one-half ounces of solution. Then add liquid ammonia to the larger portion of of the solution until it is clear; pour back the portion taken out; this will produce a muddy appearance in the solution; filter through cotton. For sugar solution take best white sugar or rock candy, one pound; water, one gallon; tartaric acid, one scruple; boil the whole 20 minutes.

—4—

Dissolve one ounce of silver in one quart of water, add one ounce of caustic potash, and clear solution with ammonia. For sugar solution take sugar, one pound; water, one gallon; boil 20 minutes; add tartaric acid, one ounce, and boil again 20 minutes. Use one ounce of silver solution to 15 to 20 drops of sugar solution.

To Solder Glass to Metals.

Make an alloy composed of 95 per cent of tin and 5 per cent of copper; melt tin first, and pour in copper while stirring well with a wooden spatula.

This should be poured granulated, and remelted. One-half to one per cent of lead or zinc makes this alloy, as hard, or fusible, as desired. The melting point of the above composition is about 600° C.

Solder for Glass.

Take 95 parts of tin, 5 parts of zinc; has a beautiful metallic lustre, adheres firmly to glass and melts at 200°.

To Stick Glass Letters to Windows.

Take one part pure India rubber (not vulcanized), three parts mastic and thirty parts chloroform; let it stand two or three days and dissolve; then apply rapidly, as it does not take it long to get thick.

Ink for Writing on Glass.

Dissolve on water bath, 10 parts bleached shellac and 5 parts Venice turpentine in 15 parts oil of turpentine; incorporate in the solution 5 parts of lamp black.

Pencil for Writing on Glass.

Stearic acid 4 parts, mutton suet 3 parts, wax 2 parts; melt together and add 6 parts of red lead and 1 part purified carbonate of potassium, previously triturated together. Set aside for an hour and then pour into hollow reeds or glass tubes.

Ink for Writing on Glass.

Dissolve 300 grains of brown lacquer in 5 ounces of alcohol without the aid of heat; then mix drop by drop with a solution of borax 2 ounces, in distilled water 8 ounces; color to suit with aniline dyes.

Acid Proof Cements.

Quick Setting.

Silicate of potassium	2 parts
Asbestos	2 parts
Sulphate of barium	3 parts

Slow Setting.

Silicate of sodium (50° Baume)	2 parts
Fine sand	1 part
Asbestos	1 part

Water Proof Cement.

Dissolve 10 parts mastic in 60 parts absolute alcohol, 20 parts isinglass in 100 parts water, 10 parts grain brandy. Mix first and second thoroughly, and add third.

To Drill Glass.

1. Use a hardened steel drill, driven at a high velocity, moistened with camphor and turpentine.

2. Use a copper drill.

3. To turn glass in a lathe use a good mill file and camphor and turpentine drip.

4. Dip a steel drill, heated to white heat, into quicksilver, which hardens it; then sharpen it on a whetstone. When drilling moisten drill with a saturated solution of camphor and oil of turpentine; keep bore hole also moist, and glass can be drilled like wood.

To Clean Glassware and Bottles.

Break a few raw egg-shells in the article to be cleaned, with a little cold water (use warm water if the article is greasy); shake well and rinse with water, and the glass will shine as nothing else will make it.

Setting Plaster of Paris.

Where it is important to have it set quick, mix it with 5 per cent solution of sodium chloride, which be made roughly by adding a tablespoon full of salt to one pint of water.

Home-Made Fire Extinguishers.

Handy about a factory is a simple fire extinguisher. M. Raymond gives the following recipe:

Water	32 parts by weight
Borax	40 to 60 parts
Anhydrous soda	80 to 120 parts
Sodium hydrate	150 to 200 parts
Ammonium carbonate	75 to 100 parts
Ammonium chloride	200 to 280 parts

This liquid thrown on or about a fire is caused to evaporate quickly, generating gases free from oxygen, which displace the air and extinguish the fire.

To Mount Photographs on Glass.

Clean the glass thoroughly. Pour on gelatine dissolved in boiling water, lay the picture on and pour on gelatin again until everything swims; neatly remove what is superfluous, avoiding blisters, and allow to dry.

No. 2.

Gelatine	16 parts by weight
Glycerine	1 part by weight
Water	32 parts by weight
Methylic alcohol	12 parts by weight

Prepare the mixture by swelling the gelatine in water; dissolve it by moderate heat; add the glycerine and stir thoroughly and pour the whole in a thin stream into the alcohol.

Order of Expansion of Different Substances.

1—Diamond.
2—Pine.
3—Graphite.
4—Marble.
5—White glass.
6—Platinum.
7—Untempered steel.
8—Cast iron.
9—Sand stone.
10—Wrought iron.
11—Tempered steel.
12—Gold.
13—Copper.
14—Bronze.
15—Brass.
16—Silver.
17—Tin.
18—Aluminum.
19—Lead.
20—Zinc.
21—Sodium chloride.
22—Ice.
23—Sulphur.
24—Ebonite.
25—Paraffin.
26—Gutta-percha; nearly 500 times as much as the diamond.

Temperatures.

Bright iron becomes yellow	435 degrees F
Bright iron becomes red	500 degrees F
Bright iron becomes indigo	550 degrees F
Bright iron becomes grey	750 degrees F
Tin melts	445 degrees F
Mercury boils	660 degrees F
Lead melts	612 degrees F
Zinc melts	775 degrees F
Silver melts	1,775 degrees F
Copper melts	1,885 degrees F
Gold melts	1,900 degrees F
Iron bar becomes red in dark room	950 degrees F
Iron bar becomes red in open air	1,450 degrees F
Annealing malleable iron	1,600 to 1,750 degrees F
Annealing glassware	800 to 1,000 degrees F

Seimens-Martin Process.

	Deg. C.	Deg. F.
Gas from producers	720	1,328
Glass furnace between pots	1,375	2,507
Glass in the pots refining	1,310	2,390

Glass in the pots working	1,045	1,913
Glass melted for casting	1,310	2,390

Method of Conducting Flame Tests.

As the analytical reactions of most raw materials respond to a "flame test," for convenience we give herewith a synopsis of methods adopted in testing by flame. (Simon's Manual of Chemistry):

"A platinum wire is cleaned by washing in hydrochloric acid and water and heating it in the flame until the latter is no longer colored, when it is dipped into the substance to be examined, and again held in the lower part of the flame, which then becomes colored. A colorless flame must be used, as an alcohol lamp or Bunsen burner, and one end of the platinum wire is fused in a short piece of glass tubing, the other end bent into a loop.

"There is a second method of showing flame reactions by mixing the substance to be examined with alcohol in a small dish; the alcohol upon being ignited shows a colored flame, especially in the dark."

Another test is called the "borax bead" test: "The compounds of some metals when fused with glass impart to it characteristic colors; this is demonstrated by the use of borax. Dip the loop of platinum wire in powdered borax and heat it in the flame (directly or by means of a blowpipe) until all water has been expelled and a colorless transparent bead has been formed. To this colorless bead a little of the finely powdered substance is added and the bead is strongly heated. The metallic compound is chemically acted upon by the boric acid, a borate being formed which colors the bead more or less intensely, according to the quantity of the metallic compound used. Some metals (copper for instance), forming two series of compounds, give different colors to the bead when present in either the higher or lower state of oxidation. By modifying the blow-pipe flame so as to either oxidize (by supplying an excess of atmospheric oxygen) or de-oxodize (by allowing some unburnt carbon to remain in the flame), the metallic compound in the bead may be made to assume the higher or lower state of oxidation. Thus a copper bead may be changed from blue to red, or red to blue, the blue bead containing the copper in cupric, the red bead in cuprious form."

Paste for Iron Molds.

Take lard oil and linseed oil equal parts, say one-half pint of each; boil down to about one-half, or until it becomes good and thick, so that when you remove some on a stick and let it cool a little while it will draw in a string like melted wax when you touch it to anything; then let it cool and add enough painter's red lead to make it about the color of mahogany, as that it gives it body. Now make some sawdust from apple wood or maple by putting the wood in a lathe and holding a file against it.

Get the mold clean and just a little warm, so the paste will spread easily; put the paste on thin with a brush, then dust it with sawdust as long as any will stick; put the mold up to heat—where it is not too hot—and bake paste until it becomes brown in color; then let it cool and blow one piece of ware in it before dipping it in water, and blow first one very easy. The best utensil to bôil paste in is a small iron pot with a cover, so that when the oil ignites it can be smothered and extinguished.

Chemical Names and Their Common Versions.

Common.	Chemical.
Aqua fortis	Nitric acid
Aqua regia	Nitric and hydrochloric acids
Blue vitrol	Sulphate of copper
Chalk.	Carbonate of calcium
Salts of tartar	Carbonate of potassium
Caustic potash	Hydrate of potassium
Common salt	Chloride of sodium
Copperas—or green vitrol	Sulphate of iron
Glauber's salt.	Sulphate of sodium
Iron pyrites.	Bi-sulphide of iron
Lime	Oxide of calcium
Lunar caustic	Nitrate of silver
Muriate of lime	Chloride of calcium
Saltpetre.	Sulphuric acid
Oil of vitrol	Nitrate of potassium
Potash	Carbonate of potassium
Realgar	Red sulphuret of arsenic
Red lead	Oxide of lead
Rust of iron	Oxide of iron
Salt cake	Sodium sulphate
Slacked lime	Calcium hydrate
Spirits of hartshorn	Ammonia
Plaster of paris	Sulphate of calcium
White vitrol	Sulphate of zinc
Bone ash	Phosphate of calcium

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